VDG
(Hughes)

FH

THE PRACTICE

OF

MAKING & REPAIRING ROADS;

OF CONSTRUCTING

FOOTPATHS, FENCES, AND DRAINS;

ALSO,

A METHOD OF COMPARING ROADS,

WITH REFERENCE TO THE POWER OF DRAUGHT REQUIRED:

With Practical Observations,

INTENDED TO

SIMPLIFY THE MODE OF ESTIMATING EARTHWORK

IN CUTTINGS AND EMBANKMENTS.

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LONDON:

JOHN WEALE, ARCHITECTURAL LIBRARY,

59, HIGH HOLBORN,

1838.

J. Barker, Printer,
9, Crane Court, Fleet Street, London.

CHAPTER I.

Observations on the necessity for a general Improvement of the common Roads.

While the important main lines of road throughout this country have arrived at a degree of excellence which may justly entitle them to some share of admiration, the general condition of our parish and other roads can leave no doubt of the fact, that the principles of roadmaking, simple and easily derivable as they are, from a few obvious truths, are yet but imperfectly understood by the surveyors and others, under whose management these roads are placed.

If the principles of roadmaking could only be applied with advantage in those cases where ample funds are at the command of the surveyor, they would be comparatively of small value to the surveyors of any but the great turnpike-roads. That the expenditure of great sums of money, however, becomes a necessary consequence of the determination to obtain a superior road, is a notion so erroneous, so dangerous and prejudicial to the public interests, that it cannot be too strongly guarded against.

In the construction of roads, as well as in most other works of engineering, the greatest amount of credit is not, as a matter of course, due to him who produces the best kind of road; because, however excellent the production may be, it is possible that its cost may have been so enormous, that, balancing on the one hand the advantage of a good road against the outlay of a disproportionately vast sum of money, the engineer after all, instead of conferring a boon upon the country, may have inflicted a serious evil. This may be considered an extreme case, but only because we rarely find that trustees are disposed to complain of their engineer or surveyor for having expended too much money, provided he succeed in constructing a very superior road. But, notwithstanding this generosity of feeling, we may readily suppose that the parties who bear the expense of constructing the road, would be at least as well pleased to obtain the same kind of road at a considerable diminution of cost. The necessity of economy in the construction of roads, without at the same time sacrificing that excellence which ought to form a primary consideration, is, perhaps, more urgent now than at any former period in the history of this country. The vast and overwhelming competition of the railway system, threatens to throw into the shade our very best turnpike-roads; but, at the same time, it requires no very profound judgment to discover, that the common roads will possess a much better chance of competition with the railroads, if the former could be improved to any considerable extent, without at the same time increasing the expenses of maintenance and of travelling over them.

The present condition of our common road system appears to call for some improvement, with a degree of earnestness not unworthy the attention of an enlightened Government. It has now became a question for their serious consideration, whether the existing roads are to be entirely supplanted, and the vast sums of money expended upon them to be sacrificed, without one effort to save them from the insatiable rapacity of the 'all-devouring railways. Is it not enough to alarm every one interested in the welfare of our ancient roads, to reflect, that the least boast indulged in by every one of the whole host of railways is, *merely*, that *all* the traffic of *all* the roads in its own direction, will at once and immediately forsake the old accustomed route, and disdaining the humble paces of eight or ten miles an hour, will flock to the railway stations, to enjoy the inestimable satisfaction of being whirled along at the rate of twenty or thirty miles an hour!

At the same time, however, that the complacent pretensions of railway companies, as we see them advanced in their prospectuses, advertisements, and reports, are sufficiently monstrous to excite a smile of incredulity on the countenance of their warmest well-wishers, it is in vain to deny that, as the means of a rapid, cheap, and certain communication, every railway will, to a great extent, attract the traffic from the neighbouring roads. We may also fully expect to see the railway system extended from the main trunks, into every town of the least importance where the chances of remuneration will at all justify the cost of construction. Many places, notwithstanding, will be left without the advantage of this rapid and cheap mode of transit; because local circumstances, arising sometimes from the difficult nature of the country to be traversed, and sometimes from the objections of landed proprietors, will often occur to prevent the formation of a railway, except at a greater outlay of capital than should ever be incurred for the purpose. Under such circumstances, it is highly important that the very best description of road should be formed to communicate with the railway; otherwise, for the towns in question, there is an end to all chance of competition with those places which possess the advantage of communicating by branch railways with the main trunk line. New roads will also in many cases be formed, in order to obtain a ready junction with the great lines of railway; and of course the strongest reasons exist for forming these new roads in the most perfect manner.

Several of the trusts on the London and Holyhead road, are at this time actively engaged, at the recommendation of the Parliamentary Commissioners, in carrying into effect extensive improvements in the line of that road. In place of resigning themselves to the fate of losing their traffic in favour of the London and Birmingham Railway, the commissioners of this road are wisely endeavouring to raise the travelling to something like an equality with that on the railway itself; and it is only by adopting such measures, that the system of common roads can be expected to stand the shock of railway competition.

But independent of the improvement of our great turnpike-roads, with the view of enabling them, as far as possible, to compete with railways, a very great necessity exists, as I have already hinted, for an extensive change in our system of parish roads. In many parts of England, where the most abundant facilities are afforded by the presence of excellent stone, to form the very best description of roads, we find the means of communication very little superior to ordinary cart tracks. The wealth and resources of many very fine agricultural districts are thus, as it were, bound up and prevented from being extended beyond the immediate neighbourhood which produces them; while every one interested in the success of agricultural operations, is well able to estimate the influence which the condition of the roads exercises upon the prospects of the farmer. The evils of ill-formed and insufficient roads, have been of late years so prominently brought into notice, and are now so generally admitted, that it will be unnecessary here to dwell on them at any length. As an instance, however, of the immense social improvement which has been effected in a neighbouring country, by means of a judicious system of inland communication, I cannot forbear adverting to the past and present state of the Highlands of Scotland. Forty years ago, in travelling through that country, the eye of the observer wandered over vast tracts of uncultivated and apparently barren moor land, which afforded a scanty subsistence to the sheep which pastured upon it. The heather and whin, or gorze-furze bushes, with the short grass peculiar to mountainous districts, composed the only crops of those uncultivated tracts, which of course were then entirely without roads or other means of internal communication. It forms a curious sequence in the chain of human events, that a boon so fraught with national benefit, as the establishment of good roads throughout the Highlands, arose out of a national calamity, of no less importance than the unfortunate rebellion of 1745. The Government, who with equal wisdom and liberality, had resolved on restoring to the country the money arising from estates at that time forfeited to the Crown, offered to advance one moiety of the sum necessary to form a perfect system of roads, on condition that the landed proprietors would raise the other moiety among themselves. This was accordingly done; and under Mr. Telford's management, as engineer, the country was intersected by roads in every direction. The result has been, that the low grounds, or glens as they are called, now abound in rich pastures, while fields of fertile corn supply the place of the wild heather of the hills, and now wave to the blast which formerly swept unresisted over a trackless moor. The inhabitants of these districts, shut out as they were from communication with the rest of the world, were well known to exist in a state of remarkable ignorance and degradation. But now their condition is widely different—the busy voice of human industry ascends from every valley—rapid strides have been made in the cultivation of many useful arts—and pauperism, at least that kind requiring the aid of charity, is almost unknown.

These are a few of the signs of prosperity and national wealth, which at once occur to the stranger travelling through this country; and if he should look further into its condition, he will find a population happy, devotional, contented with their station, and alike distinguished for moral principle and persevering industry.

The expense of the roads thus constructed throughout the North of Scotland, has certainly been very great; but it is no less true, that the advantages derived and the benefits conferred, would have amply justified, and been cheaply purchased by, the outlay even of double or treble the capital actually expended; for, in addition to the immense improvement introduced into the agriculture of the country, the whole line of coast has become the seat of extensive and flourishing fisheries, which afford employment to a vast population. Docks and harbours have been constructed in every favourable situation; while communications between places in the interior and with the coast, are made with regularity and dispatch. Every facility thus given, has well succeeded in conferring the blessings of active commerce upon a country, where industry is, perhaps, more necessary to the enjoyment of comfort, than in almost any other on the face of the globe.

Now, without meaning to infer that any part of England is so defective in the means of communication, as the Highlands of Scotland, before the improvements

I have described, and which were effected by the Highland Roads' and Bridges' Commission, I would still suggest, that some comparison might be made between the two cases; and the success which has attended the improvements made in Scotland, will at least furnish an argument for the improvement of our ordinary roads in England. It is no doubt an immense advantage to a country, to be traversed by good turnpike-roads; but the value of these is much lessened, when they can only be reached by means of the execrable roads which at present lead out of them, to the various villages and farm-houses, not situated on the exact line of road.

The farmer, in conveying his corn and other produce to market, and in sending manure to his fields, may comfort himself with the reflection, that whilst his horses are on the turnpike-road they will not be injured by the loads they have to draw; but what is their situation until they reach the turnpike-road, and after they leave it? Of course, where the turnpike lies in such a direction as not to be available, the case will be worse than where it can be partially used. But even in the most favourable case, it is evident, that the farmer must be content with a much less load than his horses could draw on the turnpike-road, unless he attempt to carry more than a fair load on the bad roads to be passed over, leading into or out of the turnpike-road. On the other hand, if he puts on a fair load for the turnpike-road, his horses will be much overloaded when they come on the inferior kind of road; because a horse, which on the former is able to draw a ton weight with ease, would probably on the latter be unable to move with more than five or six hundred weight. The injurious effects of this are too obvious to require comment; and they establish a strong reason why all roads should be reduced, as nearly as possible, to an equality in point of draught. It could hardly be expected, nor is it necessary, that the same breadth and finish should be given to all roads, which are very properly adopted on the main lines of turnpike; but I am decidedly of opinion, that all roads ought to be equally hard and solid; and I would make every parish and every occupation or farm-road throughout this country, as excellent in this essential point as the great Holyhead road itself. For roads where no great traffic exists, the breadth is of little consequence; but on this kind of road the vehicles which do pass over it are usually farm waggons, containing as heavy weights as any on the turnpike-roads. The unfrequented routes should therefore be as capable of carrying heavy traffic as the great roads themselves; and this they can only be when formed with a firm unyielding foundation, according to one or other of the methods which will hereafter be described.

I observe that, during the present session, a Bill has been brought into Parliament by Mr. Shaw Lefevre and Mr. Mildmay, "to authorize the application of a portion of the highway rates to turnpike-roads in certain cases." By the Act of the 5th and 6th Will. IV. c. 50, the performance of statute-duty for the purpose of upholding the roads was abolished; and the present Bill is intended, amongst other things, to confirm the provisions of that Act; and with this view it is proposed to be enacted, "that no person is liable to perform any statute labour upon any turnpike-road in England, or to pay any composition in money in lieu thereof."

The old method of supporting the turnpike-roads being thus abolished, the Bill proceeds to enact, that justices of peace may inquire at special sessions for highways into the revenues and condition of the repairs of turnpike-roads, and if necessary may apportion a part of the highway rate to the trustees of the turnpike-road; and the money so received is to be wholly laid out in the actual repair of such part of such turnpike-road as lies within the parish from which it was received.

It seems likely, that the condition of the turnpike-roads will be much benefited by the provisions of this Bill, should it receive the sanction of Parliament. Many of the trusts on these roads are now so seriously impoverished, that the sums they may thus claim from the highway rates will be of great service, and the farmers will also be relieved from what in some cases may be considered an oppressive burden; but whether the levying of highway rates to the extent which will be rendered necessary by this Act, will not press with undue severity in other quarters, is a question I am unable to answer. It would also be matter of great complaint, if the ordinary highways, not being turnpikes, should become worse off than at present. It would require very little argument to prove that these roads stand very much in need of improvement; and should the surveyors be rendered less able to support them than at present, we may soon expect to see them almost impassable.

I have already alluded to the necessity for some extensive improvement in our system of common roads; and as this improvement would be principally effected by means of manual labour, it might be made at a very small outlay of capital, and would afford employment to the vast numbers of paupers who now crowd the workhouses of this country. It is true, that attempts have already been made in some places to improve the roads by employing the paupers upon them; but I contend that their labour has not hitherto been properly applied, and in fact until they are made to work upon a regular system, and under proper management, it will be unreasonable to expect any remarkable result from their labours. An excellent opportunity is now afforded to the guardians of the poor throughout the country, to assign the surveyor of highways a certain number of the most able-bodied paupers, to be employed in the improvement of the common roads; and if the labourers so employed were paid a trifling sum in addition to the workhouse allowance, they would soon become useful in performing the task assigned to them. In my opinion, it is almost impossible to conceive the extent of benefit which will arise from the employment of labour in the manner I have suggested: but it is necessary to observe, that the surveyors should be made to act on a fixed system, because the country has already sufficiently suffered from the ignorance and incapacity by which too many of this class are distinguished. Written instructions in the form of specifications should be drawn out by competent engineers, practically experienced in the construction and management of roads; and to these instructions, which should be adapted to particular districts of country, the surveyors should be bound strictly to adhere. A general knowledge of the principles of roadmaking would thus be diffused, and at no distant period, we might expect to reap the advantages of this system. A scale of prices should be established for the payment of the labourers by measurement of the work performed, and not, as they are usually paid, by day work. This latter custom is extremely bad, because its certain consequence is to reduce all the workmen to one uniform state of indolence and inefficiency. To the minds of men so employed, no advantage presents itself from the exertion of any thing like superior industry. Since all the labourers are paid alike, it is evident that the best workmen, or those who under other circumstances would become good workmen, have no possible inducement to exert themselves more than the idlest and weakest of the whole gang. Hence the power and energies of these men are paralyzed to an extraordinary extent; and it is frightful to reflect on the serious and accumulated evils arising from the very injudicious way in which they are employed by the overseers. To the operation of this system alone, the overseers are indebted for repeated failures in their attempts to employ the poor with advantage. If, however, these very same men were employed at a fair remunerating price in proportion to the work they perform, there exists no reason on earth why they should fail to obtain an honest subsistence for their families; and at the same time, the parishes and the country will derive a real and solid advantage from the outlay of capital in the shape of poor rates. The advantage to be derived from the change of system I have recommended, is simply this, that the money expended in relieving able-bodied paupers, instead of producing very little or no profitable result, may be applied in the most useful manner, as part payment for the work done by paupers, in the improvement of the roads.

In the succeeding chapters I shall endeavour to point out a systematic mode of improving the roads, in which the principal ingredient will consist of actual labour. If I could show no other means of introducing effectual improvements than the application of expensive materials, and the consequent outlay of considerable funds, I should consider it useless to devote attention to the subject; but with the different opinions I have ventured to express, and with different objects in view than to recommend extravagant expenditure, I proceed to the practical details of the subject.

CHAPTER II.

On the Method of improving an existing Road.—The Figure or Profile which should be given to the Bed and Surface.—Forming the Foot-path and Fences.

As a first step to improve the condition of an old road, the direction and general levels of which cannot be altered, I should proceed to cut down high fences, if these exist, on each side of the road, and regularly to trim the hedges, so that the height of the bank and fence should not exceed four or five feet above the level of the road. The soft mud should then be scraped from the surface, and the bed of the road formed with a regular convexity of one inch in five feet, which will give in a road of thirty feet wide, a rise of nine inches in the centre. In advancing the opinion, that the bed of the road should be formed with a curved surface, I am at variance with the doctrine of many road-makers, who contend that the road material should be laid on a flat surface. The principal reason which has induced me to adopt the practice of curving the bed is, that the drainage is hereby rendered more easy and effectual, and the curved figure of the road on the upper surface is preserved, by laying on the road covering of equal depth entirely across the road. Here again a very common opinion is, that the depth of material in the centre of the road should be greater than at the sides; but for my part, I have never been able to discover why the sides of the road should be at all inferior to the middle in hardness and solidity. On the contrary, it would be a great improvement in general travelling, if carriages could be made to adhere more strictly to the rule of keeping the proper side of the road; and the reasonable inducement to this practice is obviously to make the sides equally hard and solid with the centre. In many roads, even where considerable traffic exists, the only good part of the road consists of about eight or ten feet in the centre, the sides being formed with small gravel quite unfit to carry heavy traffic; and the consequence is, that the whole crowd of vehicles is forced into the centre track of the road, thus at least doubling or trebling the wear and tear which would take place if the sides were as they ought to be, equally good with the centre. Another mischievous consequence is, that when it becomes necessary to repair the centre of the road, the carriages are driven off the only good part on to the sides, which consist of weak material, and are often even dangerous for the passage of heavily laden stage coaches. On the other hand, if equal labour and materials be expended on the whole breadth of the road, it is evident that the wear and tear will be far more uniform; and when any one part requires repair, the traffic may with safety be turned on to another part. Hence I should always lay on the same depth of material all over the road; and this alone will of course render it necessary to curve the bed of the road. With respect to the kind of curve to be formed, I think the segment of a large circle, in which the chord of thirty feet shall have a rise or versed sine of about nine inches, will form just as good a road as the segment of an ellipsis adopted by some engineers. The circle, with the circumference of which I would recommend that both the bed of the road and its upper surface should coincide, would be formed with a radius of 150 feet; and as a guide for the workman in making the proper section, it would be very useful to place in his hands a piece of board, having one of its edges curved to the proper figure, and this edge being applied to the road surface, will at once determine the correct degree of curvature.

In many roads, where the thoroughfare is not very extensive, a footpath and verge may be thought an unnecessary addition to the expenses; and certainly, in improving the ordinary farm and occupation roads, it is natural to suppose that labour and capital would be expended to the greatest advantage in forming a hard and solid track for waggons and carts. In the case of these roads, the breadth of roadway is of course not very important. It is hardly possible to form any adequate idea of the beneficial effects which would arise from the construction of even ten feet in width, of hard solid road, in place of a broken uneven surface, deeply furrowed by the frightful ruts invariably found in these roads.

In forming the bed of a road, before constructing the foundation, whether this is to consist of pitched stones or of concrete, as hereafter described, it should be borne in mind, that if the substratum be tolerably firm, the natural surface of the ground should be disturbed as little as possible. The practice of forming the bed of a road below the natural surface is decidedly bad, wherever it can be avoided. It adds considerably to the difficulty of drainage, and the only good which it can effect—namely, to form defined boundaries or edges for the carriage road-way on each side,—can be equally well done by a little earth or mould, and a turf placed on edge alongside the footpath and verge. If the road is to be metalled over a tract covered with green sward, this should be allowed to remain, and the pitching or concrete laid immediately upon it, with the exception merely, that the ground should be rounded off to the necessary convexity, the middle part or centre of the road track remaining undisturbed. Another method of forming the convexity in the bed of a road, which may often be followed with advantage, is to lay on the natural surface a sufficient quantity of the earth taken from the ditches, to form the required figure, and if this earth be well pounded, the concrete or pitching stones may safely be placed upon it. This, however, must never be attempted unless the material be hard and porous, such as sand, gravel, or rubbly rock, for any description of clay or mud would form a very unsound bottom.

The following chapters will describe so fully the method of pitching the road with stones placed on edge, and the method of forming a concrete foundation for the road material, that it will be unnecessary in this place to enter upon that part of the subject. It may not however be foreign to the business of this chapter, to make some remarks on the upper covering of the road above the pitching or concrete. In laying on this upper covering, many surveyors commit a great error in not making a distinct difference between angular or broken stones, and those rounded smooth pebbles of which gravel is usually composed. The former cannot be too well cleaned before being laid on the road, because even when entirely divested of all earthy matter, they soon become wedged and bound closely together, when the pressure of carriages comes upon them. But the case is different with the smooth round surfaces of gravel; for if this material be entirely cleaned by means of washing and repeated siftings, the pebbles will never bind, until in a great measure they become ground and worn down by the constant pressure and rubbing against each other. Before this takes place, the surface of the road must be considerably weakened, and will in fact be incapable of supporting the pressure of heavy wheels, which consequently sink into it, and meet with considerable resistance to their progress. Under these circumstances, it seems that the practice of too scrupulously cleaning the rounded pebbles of gravel, must be decidedly condemned; and the question then arises, to what extent should the cleaning process be dispensed with; or, in other words, what proportion of the binding material found in the rough gravel, as taken out of the pit, should be allowed to remain in the mass intended to be placed on the road? In answer to this inquiry I should infer, from the nature of the binding required, in order to form a proper surface for the road, that the least quantity of earthy material which ought to remain amongst the smooth pebbles, is precisely that quantity which would fill up the interstices of a portion of the clean gravel, without adding to its cubical contents. The proportion necessary for this purpose, may be determined by the following experiment: Take any given mass, say one cube yard, of perfectly clean washed gravel, entirely divested of every particle of adhering matter, and place it in a box or trough, containing the same cubical contents; then pour in water till it rises to the surface, when it is evident that the cubical capacity of the water so employed, will represent exactly that quantity of matter which will fill up all the vacuities between the pebbles, and retain them firmly in their places, under the pressure of any weight passing over them. Hence the reason for supposing that this should be the *minimum* quantity of binding material, to be left in the gravel before placing it on the road. In actual practice it may be found unnecessary to resort to this experiment; and even where it can be made, it will hardly be possible to decide on the exact kind of sieves through which the gravel should be passed, and the other processes to which it should be subjected, in order that neither more nor less than the precise proportion of earthy matter should remain in the prepared gravel. The experienced surveyor, however, would be able after a little examination to judge of the extent to which the gravel should be cleaned. A long course of experience, accompanied by attentive observations on these details in the practice of roadmaking, has convinced me, that it is much better and safer, as a general rule, to leave too much of the binding material in the gravel, than to divest it too completely of this substance. When the gravel is placed on a road without being sufficiently cleaned, the constant wear and tear, aided by the occurrence of wet weather, causes the harder material or actual gravel to be pressed close together; and the surplus of soft binding material remaining after the interstices between the pebbles are filled up, being then forced to the top, and usually mixed with water, becomes mud, and according to the usual practice should be scraped to the sides of the road. When this has been done the surface is usually firm and solid; because the hard gravel below the mud has become perfectly bound, without at the same time being broken or ground to pieces. Suppose next a road covered with gravel too much cleaned, where it is evident that the destruction of the gravel will continue until it becomes broken into angular pieces, and a sufficient quantity of pulverized material has been formed to hold the stones in their places and thus to effect the binding of the mass. I need hardly say, that the deterioration thus occasioned to the road is an evil of much more importance, and one much more to be avoided, than that occasioned by employing stones not sufficiently cleaned. Regardless of all this, however, it is the practice of many road surveyors, to insist that all gravel of whatever quality shall be rendered perfectly clean by repeated siftings, and even by washing, until at last it becomes entirely divested of all that may properly be considered the binding part of the material.

The qualities of gravel are so exceedingly various, that it is impossible to lay down any general rule as to the preparation it should undergo before being used on the road. The principal varieties consist of quartz or silex, and are usually the *detritus* of the older rocks. Considerable beds of gravel are however formed of the flints which have been washed from the upper chalk strata; and in the west of England, the *detritus* of the oolitic rocks forms extensive deposits of gravel. Those varieties usually require the least cleaning which are mixed with sharp angular particles of sand, sometimes impregnated with iron; and in fact, a great deal of this kind of gravel may be used on the roads after being once sifted, as it seldom requires any washing. Some of the flint gravel requires little preparation, except that of breaking the larger lumps to a suitable size, which should not much exceed that of a large hen's egg: but this is not always the case; for I have met with this kind of gravel in a very dirty state, much mixed with chalk and clay, and requiring a good deal of preparation before it could be used. This kind of gravel is often found deposited in extensive tracts of low flat land; but the cleanest kind of flint gravel is generally found in dry moor land, elevated above the natural drainage of the country. The following extract, from one of the specifications for an improvement on the Holyhead road, contains Mr. Telford's directions on the preparation of gravel for the road covering:—

"The eighteen feet middle of this road is to be covered with the best gravel or pebbles the country affords; it must be washed and broken, so that no stone shall remain or be put on the road that will exceed two inches and a half, or be less than one inch in diameter. All the gravel intended for the eighteen feet middle of the road to be riddled through three-quarter-inch sieves; all that passes through to be kept for the sides. The sides of the road to be of gravel, but it need not be so large as that used for the centre. It must be washed and riddled on sieves of one quarter inch meshes; the screenings to be kept for the footpath. The whole surface to be covered with one inch and a half of good binding gravel."

The following is from a specification by the same eminent engineer, in a case where the road improvement was made through the street of a town (Fenny-Stratford):—

"The whole width of pavement is to be covered with broken limestone two inches thick; the middle eighteen feet of this is then to be covered with four inches in thickness of the Hartshill stone, broken so that no piece shall exceed two inches and a half in the longest diagonal line, or be less than will pass through a sieve of three-quarter inch meshes, on which it must be riddled to free it from dirt before it is applied to the road. The sides are to be made up of good gravel, washed, sorted, and broken if necessary. No stone is to be left on the road greater than will pass through a ring of two inches diameter, and all round ones are to be broken. The largest assortment of gravel is to be put next the Hartshill stone, and the smaller sort next the sides of the road. No gravel is to be put on any part of the road that will pass through meshes of half inch square. These gravel sides are to be four inches thick at the junction with the Hartshill stone, and two inches at the sides."

FOOTPATH.—Simple as the task appears to be, it is certain that many very miserable failures have taken place in the attempt to form a good footpath. This will generally happen when the material employed for the purpose is of a clayey nature, and capable of holding water. The earth taken out of the ditches, for example, is usually very unfit to be placed in the footpaths, and should therefore be reserved to form the lower part of the mounds or banks for the quicksets. The best method of constructing a good footpath, is to raise it by layers of about three inches in thickness, composed of the scrapings of the road usually called road-drift. Silty sand, or small gravel of a binding nature, or the siftings of coarser gravel, will also form excellent footpaths. Each layer should be well pounded with a wooden rammer or pounder, about five inches in diameter, until made firm and solid, when another layer may be laid on and the process of pounding repeated. About four layers will bring the footpath to its proper level; and the surface, which should have the slight convexity of one inch in three feet, should then be smoothly raked over, and if possible should be allowed to consolidate and harden before cattle, wheelbarrows, &c. are allowed to travel upon it.

Where it may be inconvenient to obtain a sufficient quantity of road-drift, or such other material as I have described for the footpaths, it will be a very good practice to form the lower part with rubble stones, with coarse gravel, or any other porous material, on which may be laid a single three-inch layer of road-drift to form the top of the path. Before concluding these remarks on the construction of footpaths, I cannot forbear adverting to a system pursued by many road surveyors, of placing coarse gravel and large stones in the upper part of the path. Every one at all accustomed to walk on a footpath so formed, must be aware of the very unpleasant consequences to the feet; and we may readily conceive the misery occasioned to pedestrians, who are compelled to make long marches on this kind of path. The obvious rule to be followed is, that the upper part of the path should always be composed of the fine gravel or road-drift already spoken of, so that the surface of the path may be smooth and uniform as well as hard and solid,—the former of these qualities being not a bit less necessary in a good footpath than the latter.

FENCING.—In all districts of country where the fields are inclosed, it is usual and necessary to construct a fence on each side of the road to define its boundary and prevent trespass. Walls built of dry rubble stone are a very common kind of fence, in places where suitable stone abounds; and with respect to these very little need be said—their construction is so simple and generally so well understood by the country *wallers*, as they are called, that we may pass at once to the common quickset hedge more generally erected as a fence.

Different opinions are entertained as to the number of plants which should be placed in a given length, in order to form the best kind of hedge. It seems however to be generally admitted, that the quicks should be planted either when the sap is descending into the ground or ascending into the plant; that is, either in the autumn or spring of the year. Upon the whole, I think myself the autumn is the most suitable time, and if the weather be open the planting may continue through the winter. I think generally that nine good strong healthy plants in each lineal yard, that is, a single row of quicks placed four inches apart, will form an exellent hedge; although in some cases two rows are planted, containing together eighteen plants in each yard. The plants should be of not less than three years' growth, which will allow them to have been two years in the nursery-ground after being transplanted from the seedlings-bed. The mould should be of the best quality, and should be placed in the bank to the depth of at least two feet, in order that the roots of the quicksets may have sufficient room to strike. The kind of soil most suitable for quicksets is that of a light sandy or gravelly nature; and if it could be slightly mixed with peat would be much improved. A stiff clayey soil is decidedly bad; because in summer it becomes hard and dry, and in this state the smaller fibres which feed the plant cannot penetrate into it, and the quicks consequently die for want of sustenance. In winter the frost will penetrate very much into clayey soil, and not only are the plants destroyed by its expansion and contraction, but also by the excessive coldness of this kind of earth. Again, if the soil be very light and porous the bed becomes too dry in summer to afford nourishment to the plants; but I never knew a quickset hedge planted in a sandy or light gravelly soil injured through the winter. Hence the only precaution necessary in such a soil is, to prevent the destructive effects of the dry summer weather; and this I am convinced would be most effectually done if the earth could have a portion of light slimy peat mixed with it. I may mention, that the most healthy and luxuriant quickset hedges I have ever witnessed, are planted in a mould of this description. The quicksets, if properly planted and well cleaned and weeded twice a year, ought to grow up into a tolerable hedge in about three years; although to prevent it from being broken through too soon, it may be advisable to allow the post and rail-fence to remain as an additional protection for five or six years;

until in fact the timber becomes worn out and destroyed, which it usually is by that time.

Some hedges, however, require a much longer time to acquire anything like the strength of a fence; but in such cases the failure is usually attributable to improper management and unsuitable soil. A long tough description of couch grass, with strong roots, is very apt to grow up with the young shoots; and unless this enemy be carefully destroyed, at least twice a year, it is in vain to expect the quicks to acquire a healthy growth. But probably the most extensive kind of destruction is that occasioned by the calves and sheep passing along the road, or pasturing in the adjoining fields. These animals, and particularly the sheep, are remarkably fond of the green juicy heads of the young shoots, which they bite off whenever they can reach them; and this practice alone, if allowed to continue, will always prevent the quicksets exposed to it from attaining their proper size and strength. The method of guarding against this source of injury, is obviously to place the post and rail-fence at such a distance from the quicksets, as to make the latter beyond the reach of the sheep and calves which are in the habit of thrusting their heads through the openings between the rails, in order to obtain this very favourite kind of food. For want of attention to this precaution, many hedges, which would probably have formed very fine fences, have to this day produced nothing but stunted imperfect shoots, thus of course entirely failing to realize all expectations of ever growing up. In many road specifications the directions to the contractor have been, to place the post and rail-fence so near to the quicksets, that they must infallibly be destroyed from the cause I have mentioned; and the result has been, in almost all such cases, that the attempt to procure a good fence has entirely failed.

CHAPTER III.

On the Improvement of Roads by means of pitching the Bottom with Stones placed on Edge, as adopted by Mr. Telford on the London and Holyhead Road.

In those districts where granite or the older stratified rocks prevail, the roadmaker possesses the advantage of having at command the very best possible materials for constructing a perfectly hard and solid road. So highly has granite been prized as a covering for roads in the neighbourhood of the metropolis, on which of course immense traffic exists, that this material has been procured from the island of Guernsey, from Dartmoor forest in Devonshire, and other places, at an expense of not less that a guinea per ton. Of all the granites ever used as a road-covering, the Guernsey is esteemed the best; and from a series of experiments made under the direction of Mr. Walker, President of the Institution of Civil Engineers, it appears, that the wear of different kinds of granite is in the following order: Guernsey, Herm, Peterhead (blue), Heytor, Aberdeen (red), Dartmoor, Aberdeen (blue.)

The grand distinction between the granite and limestone rocks, even of the hardest class, is, that the former are far more capable than the latter of resisting disintegration by the action of water and frost; and as they possess in an eminent degree the qualities of hardness and durability, they may safely be used, either in the shape of blocks to form the foundation of the road, or, when broken to a suitable size, may be applied as a top covering with which the wheels are to be in immediate contact. If the bed of a road, after being made perfectly dry, be covered over with a layer of broken granite, the angular shape of the stones will allow them to wedge and dovetail as it were into each other, so that when pressed by the wheels rolling over them, the whole will form a solid resisting mass of great stability and hardness. Hence, although I would recommend that a regular foundation made in the manner hereafter described, be laid down in all roads where anything like extensive traffic is to be carried on, yet if it were asked in what case this foundation might with the least injury be dispensed with, I should answer, in that situation where the road metal consists of broken granite. In no other case than this, however, should the general rule on any account be departed from, of constructing a solid artificial foundation before laying on the top covering. Even on the score of economy, the road pitching should be adopted in preference to the broken stone metalling, because it will be found cheaper to pitch the road with hard stones than to break them up for a road covering.

Two distinct kinds of road foundation will be described in the following chapters, namely—first, the *pitched bottom foundation* mentioned above, which was introduced by Mr. Telford, and which consists of a close firm pavement of stones, placed side by side on their broadest base; and next, the *concrete foundation*, composed of gravel or broken stone, mixed in proper proportions with lime or cement. The former of these two kinds will be applicable to those districts where, in place of granite and whin, the stratified rocks of limestone and sandstone prevail—to every situation, in fact, where any description of stone can be procured at a reasonable price.

Although some kinds of sandstone are tolerably hard, the prevailing characteristic is that of a dry brittle rock, easily broken and easily ground to powder, therefore generally very unfit for the purpose of a road covering. All kinds of limestone are still more inapplicable as a top coating than sandstone. It has often been observed, that in dry weather limestone forms an excellent road; but owing to the capacity of this material for water, the slightest rain produces an almost instantaneous effect on this kind of road. A surface, which in dry weather is, perhaps, perfectly hard and smooth, becomes after a shower of rain a complete puddle: the water renders the stone quite soft, and in this state it is soon ground into mud. Where there is much traffic, a very short continuance of wet weather will complete the destruction of a coating six or eight inches in thickness, which under these circumstances will be cut through by the wheels in a marvellously short space of time. If the mud be not immediately scraped away, it becomes very clammy in the process of drying, and in this state the road naturally requires a very heavy power of draught. In dry weather the mud formed during wet seasons becomes dust; and in roads of this kind it usually exists to an extent seriously annoying to the unfortunate travellers, who sometimes can hardly escape being smothered.

Should a frost occur the limestone road will suffer much more than from the rain—the moisture which this kind of stone so copiously imbibes, will be expanded by the action of the frost to a larger bulk than when in the liquid form; and the consequence of this is an immediate shattering and bursting of the stone, which in many cases is almost reduced to powder, or at any rate is rendered capable of being crushed by the first wheel which may pass over it. As soon as the sun begins to melt the frost, the limestone covering becomes ten times more adhesive than ever: it may now with truth be compared to birdlime, so tenaciously it adheres to the wheels of the carriages. The work of destruction becomes rapid and astonishing in its effects; the whole road is torn to pieces, immense patches of the covering are entirely stripped from the surface, and the road deeply indented with large hollows. Such are the effects produced even on the best kind of limestone road by a few nights of slight frost, succeeded by the fine sunny mornings of autumn and some of the mild winters. Upon the whole, the objections to limestone are so numerous and so well founded, that this material should never in any situation be used as an upper covering, or road metalling.

In condemning the use of broken lime and sandstone as an upper covering, I would however except the hard varieties of the latter which contain iron. Sandstone of this kind, found in the green sand ranges of Surrey and Sussex, is extensively applied on the neighbouring roads, where the surface formed by this kind of stone is extremely hard, and indicates a very small amount of friction. On a part of the Surrey and Sussex road, in the neighbourhood of Red Hill, I have been forcibly struck with the excellent surface formed by this kind of stone. Although not in possession of any actual experiment on the amount of friction, yet from having passed over it a great number of times, and from observing the ease and speed with which horses drawing carriages, coaches, and gigs, are able to ascend hills of considerable acclivity on which this stone has been laid down, I should venture to predict, that the friction is not more than on the best granite road I ever saw. The same kind of iron sandstone is found at Pulborough, and other parts of the sand range underlying the South

Down chalk hills; and there also it has been extensively used as a road material, particularly between Pulborough and Billinghurst, a part of the road acknowledged, by the coachmen and others acquainted with it, to be the best between London and Arundel.

Whilst, however, no doubt can be entertained of the general unfitness of limestone and the softer kinds of sandstone for the upper covering of a road, we are indebted to the late Mr. Telford for the knowledge of a most admirable application of these kinds of stone to the purposes of roadmaking. Proceeding on the principle, that next to the efficient and thorough drainage of a road, the securing a good, hard, firm foundation is the most important object to be attended to, that eminent engineer directs, in his specifications for works on the London and Holyhead road, that "upon the new surface or level space prepared for the road material, a foundation of limestone, sand, or marlstone is to be laid in the form of a close firm pavement. The depth of each stone is to be seven inches in the middle of the road, and five inches at the sides; the stones are to be set lengthwise across the road, they are to be laid on their broadest edge, and the breadth of the upper edge is in no case to exceed four inches; all the inequalities in the upper part of the pavement are to be broken off with the hammer, and all the interstices filled with stone chips, firmly wedged or packed by hand and a light hammer, so as to form a regular convexity of one inch in nine feet from the centre, and three inches at the channels, or at the distance of fifteen feet from the centre."

The kind of pitching here described consisted of sand and limestone, which would have been quite inapplicable as a top coating for the road; but which was found, when covered by a layer of gravel or hard broken stone, to form a most excellent road. It is true, that when this method of road pitching was first adopted, the opinions of several scientific engineers were opposed to it; but the superiority it possesses over the ordinary mode of laying on the gravel or broken stone in a body, has now become so evident, that few persons are any longer disposed to doubt the merit of its introduction into the practice of roadmaking.

Surveyors, therefore, in those districts which do not produce the harder kinds of rock, have, in the way described, an opportunity of employing to great advantage the inferior descriptions of stone, which are very commonly found all over England. The adoption of this method is recommended by numerous considerations, more especially to all those parishes which are burdened by a large number of paupers. The stone to be used for the pitching, after being quarried, requires very little breaking; because sandstone, and the upper or less valuable beds of limestone, are generally quarried as waste or spare rubble, in pieces of about the proper size for road pitching; and most quarries produce more of this stuff than can be worked up in any building. The price of this kind of stone at some quarries is threepence a cart-load; and I never knew more than sixpence charged. In some places, however, where the quarry has to be newly opened, it may cost a shilling per cube yard; but if the quarry be situated on a common or waste piece of land, the stone costs the parish nothing but the labour of the workmen.

The principal expense then, besides that of carting from the quarry to the road, is the labour of pitching the stones by hand; and the art of performing this kind of work with neatness and expedition is very soon learned by a labourer of ordinary capacity. The price usually paid for the actual labour of laying down the pitching on the Holyhead road, is from one shilling to fourteen pence per lineal yard of 30 feet wide; and a workman of tolerable industry can with ease lay down about four yards in length per day.

The practice of forming a pitched foundation, as described in the preceding extract from one of Mr. Telford's specifications, having been employed with great success in most of the improvements executed on the Holyhead road, has thus received the valuable sanction of practical experience; and may safely be recommended as an effectual cure for those troublesome cases in roadmaking, where the stratum composing the bed of the road displays a tendency to burst through and mix with the road materials. It is vain to argue, that a great body of gravel or broken stone will of itself prove sufficient to prevent the sub-soil from rising. To those who adopt an idea so erroneous, I would simply observe, that they can never have been acquainted with any very difficult cases of this kind. I have myself, in breaking up old roads, found layer upon layer of excellent gravel to the depth sometimes of not less than four feet, but completely mixed with the clayey material which had found its way from beneath. Where a road happened to be carried over this kind of material, and it was found to mix with the gravel which formed the covering of the road, the old system, for the most part, recognized no other practice of stopping the evil than that of loading the road with a further quantity of gravel or broken stone—an application which proved of an extremely temporizing and imperfect character; because no sooner had one layer of gravel become mixed with the sub-soil, than the latter rose into the coating last put on, and the whole mass of road material became reduced to the same clogged and spongy condition as before the application of the new gravel. In all obstinate cases of this kind, however, the pitched foundation will most effectually prevent any rising of the sub-soil, and the gravel laid on as an upper coating will then have a fair chance of binding and becoming sufficiently hard and solid to form a good travelling surface.

In the following chapter will be found some account of the method resorted to for the improvement of the Highgate Archway Road, after it was placed under the management of Mr. Telford. I had in that case actual and ocular demonstration, that the various processes of laying brushwood and tin chippings in the bed of the road had previously been adopted; and in many other cases, I have seen the remains of fagots which had been interposed between the upper coating of gravel and the sub-soil, which it was vainly anticipated would in this way be prevented from rising. It would seem that those old roadmakers, who have so tortured their inventive faculties to devise means for securing a firm foundation for the upper coating of the road, would hardly agree to some of the axioms laid down by a modern road surveyor of eminence, whose name, with an appropriate termination, has been introduced into the English language to distinguish the system of road-making of which he is the author. According to this gentleman, "it is no matter whether the sub-stratum of a road be hard or soft." The advocate of a doctrine so heterodox might derive an useful lesson from the experience of those old roadmakers, who were evidently at so much pains to correct and obviate the misfortune of a soft sub-stratum. I can scarcely help thinking, that such a doctrine could only have originated from a very superficial acquaintance even with the existing condition of roads. To most persons in the habit of practising anything like observation as they pass through life, there are few differences more striking than that between a road formed on a soft foundation, and one which has the advantage to pass over a hard substratum.

The great principle of utility is strikingly consulted in Mr. Telford's practice of pitching the foundation of the road; for it must be borne in mind, that the materials to be used for this purpose would for the most part be utterly useless for a top covering, and yet when employed as a pitching in the way before described, an extremely durable and excellent road is the result. If road surveyors could only be prevailed on to adopt the system of pitching their roads with such materials as are found pretty generally throughout this country, I am certain they would soon find, in the superior character of the roads they would be enabled to form, ample cause to congratulate themselves on having stepped aside from the old practice of loading the road with enormous quantities of gravel or broken stone.

In considering the quality of stone proper for the purposes of road pitching, it is an error to suppose that none but very hard stone should be used. The soft kinds of sandstone and freestone, and very inferior kinds of limestone, have been extensively used on the Holyhead road; and I am persuaded that blocks of chalk, particularly of the kind called rock-chalk, would form a very excellent material for pitching. In any case, however, where chalk or even limestone is used for pitching, the drainage of the road becomes of more than ordinary importance. In order to preserve this material, it is absolutely necessary to protect it from the atmosphere, whence it would otherwise imbibe moisture which would shortly produce very destructive effects; and the precaution of protecting the pitching from the air will evidently be entirely useless, unless the bed of the road be first made perfectly dry; but if this duty be effectually attended to, chalk itself, and the softer kinds of limestone rock, will resist the progress of decay for a very long time.

CHAPTER IV.

On the Improvement of the Highgate Archway Road, by means of a Concrete Foundation, composed of Gravel and Cement.

THE first effectual method adopted for the improvement of this road, was executed under Mr. Telford's directions in the year 1828; and for some time the new kind of foundation then introduced, consisted of moulded bricks formed of gravel and Parker's cement. The process of making and laying these concrete bricks was however found to be very expensive, and many practical difficulties attended their use. It was impossible to prevent them from breaking and falling to pieces when taken out of the moulds, and from crumbling and breaking when placed in the heaps to undergo the process of drying; whilst many others, which had up to that time remained whole, were broken to pieces in the act of removal by carts, although this operation was performed with the utmost care, and straw placed between each course to prevent breakage. In this way I am quite safe in asserting, that at least one-third of the whole quantity of moulded bricks were lost. In consequence of these numerous objections, the practice of using the bricks was at my suggestion eventually abandoned, Mr. Telford directing that the concrete should be laid in mass without being moulded into the form of bricks; and from this period the mixture was made up in a wooden trough on the ground, and then carefully placed in the bed of the road; and before it was allowed to get hard, a wooden mould shaped thus, like the letter V, was stamped transversely at the distance of every foot apart, in order to allow any water to drain down this indented channel into the side drain, and also, that the covering of stone or gravel might more easily bind and become solid on the concrete. This method, although a great improvement on the first plan, was very expensive and tedious, principally on account of that property in the cement by reason of which it sets and becomes hard, in a remarkably short time after being formed into concrete—a property which rendered it necessary that only a very small quantity should be prepared and laid at one time.

The following short statement shows the proportions of gravel and cement used for the concrete :—

One bushel of cement made 30 bricks = 5 cube feet.
One barrel of cement made 150 bricks = 25 do.

The bushel contains 2218 cube inches; and 30 bricks contain 8640 cube inches, leaving 6422 cube inches of gravel. Hence the proportion of cement to gravel is that of 2218 : 6422, or as 22 to 64, or in round numbers about 1 of cement to 3 of gravel.

Although on account of the breakage and loss sustained, I am not in possession of sufficient data to determine with accuracy the cost of pitching the road with bricks, the following estimate of the actual expense of forming the concrete bottom will furnish some idea of the increased expense which must have attended the use of the bricks.

Four men mixed and laid about 8 lineal yards of concrete, 7 feet 6 inches wide and 6 inches deep—this being equal to 8 yards $\times$ $2\frac{1}{2}$ $\times$ 0.166 yards = $3\frac{1}{3}$ cube yards: therefore 12 men would lay 10 cube yards of concrete per day. And dividing this quantity in the ratio of 11 to 32, we find that 12 men would use per day 50 bushels of cement and 7.44 cube yards of gravel. Hence the following estimate:—

	£	s.	d.
Cement, 50 bushels, at 2*s*. . . .	5	0	0
Gravel,* 7.44 cube yards, at 8*s*. . .	2	19	6
Labourers, 12 men, at 3	1	16	0
Cost of 10 yards cube, or 12 lineal yards, 15 feet wide, ...	9	15	6

From this we see that the cost of the concrete was 19*s*. 6*d*. per cube yard, or 16*s*. 3*d*. per lineal yard of 15 feet wide. It should be noticed, in detailing the price of the gravel at 8*s*. per cube yard, that the unfavourable circumstances in which the work at Highgate was placed, with reference to the supply of gravel, were certainly rather unusual. This material could only be obtained at a considerable distance from the works; and when dug required great care to be taken in the washing and screening, in order to render it perfectly devoid of earthy matter before mixing it in the concrete—the consequence was, that none of the gravel used in the Highgate Archway road cost less per yard than the sum mentioned in the preceding estimate.

It may not be irrelevant to state here, that the Archway road, to which this description of the work relates, was, at the time when it came under the superintendence of Mr. Telford, probably one of the worst pieces of road in the kingdom; and, notwithstanding the consultations of engineers and other scientific men which had frequently taken place, and the various attempts which had been made by them to render this a

* Gravel at Highgate, carted from the Thames, including tolls, &c. would not cost less than is here stated;—if from Finchley, or that neighbourhood, the carting, waste, and washing to render it fit to mix with cement, made it equally expensive.

good travelling road, every attempt and trial, although attended by the expenditure of many thousand pounds, and almost by the insolvency of the Highgate Archway Company, was found to be ineffectual in producing anything like a permanent improvement in the condition of the road. These various attempts, in fact, were dictated by such remarkable ignorance of practical principles, that instead of diminishing or removing, it has been supposed they actually ended by increasing the evil. The geological strata composing the hill through which the road is carried, are those of the London Clay Basin: they contain a considerable mixture of sand and gravel, which being permeable materials, are consequently full of water. No systematic form of draining had ever been considered by the scientific men who were consulted; and as the consequence of this neglect throughout the winter, and in all wet seasons, springs of water were numerous, not only in the sides of the excavations but even in the middle of the road. It followed, therefore, that any depth of covering intended to keep the under stratum from rising amongst the gravel or hard material proved quite ineffectual; for as fast as new materials were laid on they were pressed into the soft bottom, and mud, clay, and sand supplied their places. It has been considered, and with great truth, that this piece of road has occasioned more loss to coach-horse proprietors than any other of the same extent either in this or in any other country.

The first determination formed by the authorities of the day, after an examination of the road and all the causes of its defects, was to have the existing surface taken entirely out—the whole bed was to be then covered with brushwood fagots, and this again to be covered over with a good and sufficient coating of excellent clean gravel. That this was far from being a cheap experiment I need hardly say, whether it were a good one had then to be tried. The result naturally followed, which any practical man would have foreseen—the road, whilst the gravel was loose and the brushwood not compressed, was perfectly dry on the surface; but in consequence of the great depth of loose gravel and the elastic nature of the brushwood foundation, nothing in my opinion could have been better devised for the destruction of horses than this truly infamous piece of road.* This was the state of things when the road remained unbound; but as soon as by compression the fagots were nearly rotten and made solid, and when it was expected that the gravel would bind and a solid surface be formed, instead of this the gravel was all nearly ground to dust: and certainly out of the expensive materials laid on the road there was nothing left but coarse grit. This material, I need hardly say, was more unfit to carry the traffic than that which they had taken up to make room for it; and the perishable fagots having now become rotten, there was nothing to prevent the mud and clay from mixing with the upper covering. The whole road was now ten times worse than ever; and a material of a character very novel in the history of road-making was fixed upon in carrying into effect a third attempt to improve the road. This was no other than the refuse or waste chippings of tin; in order to make room for which the old surface was again torn up, and the whole bed covered with several inches in depth of the *tin chippings*—a fact which accounted for the discovery, when I came to put into execution Mr. Telford's plan of forming a cemented bottom, of several tons of this material in a state of partial rust, and in

* The inclination of the hill, on which the coaches had to be dragged fully half a mile, was about 1 in 30.

some places knotted and kneaded into the clay, gravel, and some small portions of the fagots, which had probably not been taken entirely away. I think I need hardly say that, notwithstanding the sanguine expectations of those who were induced to adopt the novel expedient of thus forming an actual metallic sub-stratum for the road covering to rest upon, the plan I have just described, although no cheaper than those resulting from former deliberations, proved as complete a failure as any which had preceded.

It is perfectly well known, that this same Highgate Archway road, which had so pertinaciously resisted all exertions to improve it on the part of former engineers, became, under the management of Mr. Telford, one of the very best roads in the kingdom. Mr. M'Neil, I believe, showed by means of his friction-testing machine, that the power required for draught on this road was less than on almost any other which had been tried in the same way; and the superiority thus indicated, is fully confirmed by the testimony of the stage-coachmen and others driving over this part of the Holyhead road.

At the same time, however, that every one at all acquainted with the subject is ready to admit the extent and importance of the change for the better which has taken place in the condition of the Archway road since the adoption of the cemented bottom, it follows by no means as a necessary consequence, that this improvement is entirely the effect of the particular kind of foundation or sub-stratum on which the road material is now laid. In order to be convinced of this, and also that, knowing all the actual means of improvement, we may derive the greatest amount of practical experience, we must consider the merit of the very excellent drainage devised by Mr. Telford, and which I believe was on a far more extensive scale, and therefore more likely to be beneficial than any that had been adopted by his predecessors in the management of this road. As it may be useful to the road surveyor generally, to know the system of drainage which was at length so effectually acted upon, I shall not hesitate to describe it in detail. Along the whole length, and on each side of the road, longitudinal side drains were cut, two feet wide and four feet deep, below the bed of the road. Longitudinal shoulder drains, one foot deep, were also cut the whole length of the road on each side of the cemented bottom—that is seven feet and a half on each side the centre of the road—and transverse mitre drains, opening into the shoulder and side drains, were formed across the road at intervals of from fifteen to twenty-five yards. The deep side drains had a tile and sough cover five inches diameter laid in the bottom, and above this the drain was filled in eighteen inches wide with clean stones, the space of six inches between the sides of the drain and the road side being filled with clay and well pounded. The other drains had no sough or tile, but like the side drains were filled to the top with clean stones.

It was the natural result of a drainage so complete as that which I have described, that water falling on surface of the road could not lodge in the bottom, and in this way keep the road in a soft and wet state, but would immediately be conveyed into the shoulder or side drains quite clear of the road; and with respect to water which arose in springs at the side of the road, this was provided for by the side drains, which effectually cut off all these springs and diverted them along the road side.

But in reverting to the state of this road before the existence of the drains, we are presented with a wide contrast to that in which it was afterwards placed by the judicious measures of Mr. Telford. It was formerly found that the natural springs, which abundantly existed in the high ground on each side of the road, discharged themselves in the bottom and sides of the excavation; and before the necessary means were taken to prevent them reaching this situation, the bed of the road remained constantly wet and saturated with water. This is a case by no means peculiar to the Highgate road: I have met with it in many others, where, as in the present instance, the construction of deep and capacious side drains, which acted as channels to cut off and divert the water from entering the confines of the road, proved the only effectual remedy. We may now readily conceive the grand secret of all the previous failures in the various attempts made to improve this road;—it is perfectly evident, that so long as the clayey bed of the road continued to be saturated with water, it was capable of displacement by any weight passing over it; and thus no means could be invented to prevent it from rising, and mixing with each successive body of materials laid upon the road.

CHAPTER V.

On the Use of Concrete composed of Gravel and Lime, as a Foundation for Roads in places where pitching Stones cannot be procured.

THE descriptions of stone which might with propriety be used for a pitched foundation are so various, and are so extensively found throughout England, that in few counties the surveyors are without the means of adopting that method of securing a hard substantial road. Nevertheless, in the neighbourhood of London, and in some other districts, particularly Norfolk, Suffolk, Cambridge, and the adjoining counties, where the place of the stratified rocks is supplied by beds of gravel, it will be found an expensive, and in some cases almost an impracticable proceeding, to procure and lay down stones, as a pitched foundation for the road material to rest upon. I should by no means recommend the adoption of this kind of foundation in places where the expense would exceed the price of concrete, or say from 3*s.* to 6*s.* per cubic yard; and shall therefore now proceed to point out the way in which gravel itself may be applied to the purpose of securing as hard and firm a road, and one as little subject to destruction, as any that could be formed in a country where the hardest kinds of stone are within the reach of the surveyor.

The concrete I am about to describe will be different in one important particular from that used on the Highgate Archway road, although intended to effect the same object, of preventing the sub-stratum on which the road is formed from being displaced, and from rising up to mix with the superior stratum of road material. In some respects the concrete of lime, although much cheaper than that formed with cement, possesses advantages over the latter; but if it should hence be inferred, that the expense of the cemented bottom at Highgate was on this account unnecessary and wasteful, it must be remembered, as some apology, that the virtues of lime in forming concrete were not then so extensively known as they have since become; and had this work now to be performed, I have no doubt that the concrete of lime would be used in preference to cement.

The principal difference between the two kinds of concrete, arises from the liability of cement to break and crumble when exposed to pressure, to percussion, or to any other violent disturbing force; and when once a fracture has taken place, it is a characteristic of cement that the parts will never again unite. Therefore it is that cement, although extremely valuable as a means of forming a very solid artificial stone, by uniting into one mass a body of broken stone or pebbles—and although it possesses the remarkable property of setting in all situations, even under water, in a very short time after its mixture—is yet hardly a safe material to use in any place where it is subject to the disturbances already mentioned, by which the adhesion of its constituent parts will certainly be destroyed; and this having once taken place the whole binding virtue of the cement is gone.

I regret that I have never had an opportunity of seeing a specimen of the cemented bottom taken from the Highgate Archway road, after it had been laid down a sufficient length of time to prove its durability. If such a specimen could be procured, it is not improbable that it would be found in a fractured condition; and this would of course prove a very strong confirmation of the notion with which I am now very strongly impressed, that *lime* concrete, from the greater degree of toughness it possesses, and the consequent absence of that brittleness and tendency to break which are so remarkable in cement, is actually much the superior material of the two as a foundation for roads.

The use of lime concrete, although an introduction of modern times, and certainly one of rather a novel character, derives its real origin from a very remote period. We have indisputable evidence that the Romans in constructing their military ways, particularly in France, adopted the practice of forming a concrete foundation composed of gravel and lime, on which also they placed large stones as a pavement. The consequence of a construction so solid has been, that in many parts of Europe the original bed or crust of the Roman roads is not at the present day entirely worn down, even after a lapse of fifteen centuries.

With the view of affording a modern example in which lime concrete has been used, I would refer to the Brixton road, where a concrete composed of gravel and lime has been recently applied by Mr. Charles Penfold, surveyor to the trust. In this case the proportion of gravel to lime is that of 4 to 1. The lime is obtained from Merstham or Dorking, and before being used is thoroughly ground to powder. The concrete is made on the surface of the road, and great care taken, when the water is added, that every particle of the lime is properly slaked and saturated. The bed of concrete having been spread to the depth of six inches over the half breadth of the road, the surface is then covered over with six inches of good hard gravel or broken stone, and this depth is laid on in two courses of three inches at a time, the first course being frequently laid on a few hours after the concrete has been placed in the road. The carriages however are not on any account allowed to pass over it, until the concrete has become sufficiently hard and solid to carry the traffic, without suffering the road material to sink and be pressed into the body of concrete. On the other hand, the covering of gravel is always laid on before the concrete has become quite hard, in order to admit of a more perfect binding and junction between the two beds, than would take place if the concrete were suffered to become hard before laying on the first covering. The beneficial effect arising from the practice of laying on the gravel exactly at the proper time is, that the lower stones, pressed by their own weight and by those above them, sink partially into the concrete, and thus remain fixed in a matrix, from which they could not easily be dislodged. The lower pebbles being thus fixed, and their rolling motion consequently prevented, an immediate tendency to bind is communicated to the rest of the material—a fact which must be evident, if we consider that the state called binding, or rather that produced by the *binding*, is nothing more than the solidity arising from the complete fixing and wedging of every part of the covering, so that the pebbles no longer possess the power of moving about and rubbing against each other. It is found that, in a very few days after the first layer has been run upon, the other or top covering may be applied, and shortly afterwards the concrete and the whole body of road material becomes perfectly solid from top to bottom. The contrast thus presented to the length of time and trouble required to effect the binding of road materials, where the whole mass is laid on loose, is alone a very strong recommendation in favour of the concrete.

The experiment of using concrete on the Brixton road, although not at present on a very extensive scale, has been tried under circumstances very far from favourable, and on a part of the road which had hitherto baffled every attempt to make it solid. Since the concrete has been laid down, however, there is not a firmer piece of road in the whole trust; and from the success of this and other trials made by Mr. Penfold, but which I have not seen, I believe it is his intention to recommend it in a general and extensive way to several trusts under whom he acts.

The use of concrete for building purposes, where great solidity is required, has now become very general and cannot be too strongly recommended. We have now examples of a very extensive sea-wall, and of several dock and wharf-walls, and even of a church, built entirely of concrete. In some of these cases, particularly in that of the sea-wall at Brighton, the lime used for the concrete is slightly hydraulic, possessing therefore the property of setting under water. In some roads where the concrete is laid upon a damp sub-soil this quality will be useful; but it is by no means essential to the formation of a perfect concrete, as any description of hard strong stone lime will admirably answer the purpose. From the experience of the sea-wall at Brighton, we derive the knowledge of a fact, which may prove of some value to those who may have occasion to use concrete in the neighbourhood of the coast, namely, that the salt water of the sea makes excellent mortar, and the pebbles of the sea shore form excellent material for mixing with the lime to make concrete. There is, therefore, good reason for supposing the prejudice to be groundless, which is entertained by many engineers and architects, against the employment of any material containing saline particles, in making either mortar or concrete.

I should here mention, that while the improvement described in the preceding chapter was in progress on the Highgate Archway road, one particular spot of the road about four feet square, near the Wellington Inn, being found extremely soft and elastic, I tried here on my own responsibility a concrete composed of gravel and blue lias stone lime, which was substituted for the cement concrete, and the result of this certainly was to render that part of the road as perfect as all the rest.

In consequence of this trial, strengthened by a very strong notion of my own that lime concrete would be found at least equally effective with that of cement, I consulted Mr. Rhodes, civil engineer, on the subject, as he had always taken great interest in the improvement of this road; and his opinion determined me to request permission from Mr. Telford to lay down a small quantity of the lias lime concrete on another part of the work. Mr. Telford having afterwards agreed to this at the further suggestion of Mr. Rhodes and Mr. M'Neil, it was accordingly tried on a short length of the road near the summit of the hill. The trial, I should state, was not made until after I had finished my contract for the work; and I regret to say, that the time chosen was very injudicious, and no precautions to protect it from the weather being taken, the frost completely destroyed the lime, and the concrete was never allowed properly to set. In consequence of this failure, it was reported that the lime concrete could not be used as a substitute for the cemented bottom; and notwithstanding the completely successful and very satisfactory trial I had myself made at the Wellington Inn, the idea of using lime concrete was abandoned. It will only be fair towards Mr. M'Neil, however, to acquit him entirely of all blame for the failure of the trial made after I had left the work. I believe it was his intention fairly to have tried the lime concrete; but from some cause or other with which I am not acquainted, he was prevented from attending to it himself; and the person he entrusted having neglected it, I do not think Mr. M'Neil ever knew the cause of the failure.

Without however drawing any inference as to the value of lime concrete, from the trials made on the Highgate road, I am decidedly of opinion that this material, if generally adopted as a foundation for roads, will effect one of the greatest improvements that has for many years been presented to the notice of the public. In the neighbourhood of the metropolis particularly, where durable materials are so exceedingly expensive, and where the Thames gravel can be had at such a cheap rate, the expense of constructing the best description of road will be very much diminished. The Thames gravel can be delivered, at a distance of from two to three miles from the river, at about 3*s.* per cubic yard; hard flints and well prepared pit gravel at about 6*s.* or 6*s.* 6*d.* per yard; Guernsey granite, Mountsorrel, Dartmoor, Haytor, or Scotch granite, from 15*s.* to 20*s.* per cube yard. I am clearly of opinion, that the first of these materials—the river gravel—ought never to be used as an upper covering or surface for any road of much traffic, even if it could be had for nothing. From its extremely brittle nature, it not only crumbles and breaks to pieces immediately when pressure comes upon it, but it actually is decomposed, and crumbles into sand and grit when acted upon by the alternations of the weather alone. On account also of its round and smooth surfaces, which are perfectly divested of all material of an adhesive nature, the binding of this gravel is entirely out of the question until it be made angular; and this never happens except when the whole is ground into such small particles as to render it quite unfit for a carriage road. The consequence is, that this gravel no sooner begins to bind or set, than the first rain or thaw, after ever so slight a frost, renders it quite impassable; and hence it is, that where this material is much used on the metropolitan roads, the public can never have the advantages of a solid, hard, and firm surface for any length of time. Even in the very best summer weather such a road cannot stand many days; the public are therefore constantly annoyed, either with a new covering, which occasions an immense friction and great wear and tear of horses and gear of every description, or they have to travel on a road which is so soft that the wheels of carriages sink into it with perfect facility—in either case the friction, and consequent destruction of horses, carriages, and harness, and the annoyance to those who travel on it, must be excessive. When we take further into consideration the number of men who must be in constant attendance to rake in the ruts, and to clear the road of the useless materials when ground to pieces, and also the constant expense of laying on new materials, I think few will be inclined to dispute with me the impolicy of using river gravel as an upper covering on the metropolitan roads. Since, then, it cannot be profitably or judiciously used as an upper covering, it would be obviously improper to apply it as a bed on which to place the harder stone, which forms the road material. This must be evident, from the well known fact, that the binding and setting of any road covering, however deep, always commences at the bottom of the material; and it will occur to every one who considers the subject, that no binding of a stronger and heavier material can take place on another of a softer or lighter description than itself; because the upper material, being the harder and stronger of the two, will sink down and press the other aside instead of uniting with and binding into it. In this way the softer material would evidently very soon be destroyed; because, until the binding of a road covering takes place, the friction and rubbing of the stones amongst themselves is very considerable and very destructive. The effect of this may readily be conceived in the case of a soft brittle material like the river gravel, mixed up as it soon would be with a hard silicious granite or whinstone. Experience in fact has shown, in a great number of cases, that it is quite impossible to produce effectual binding unless the bottom be solid, and to a certain extent unyielding; and hence, if two or more varieties of materials are to be used in the covering, the hardest must be placed in the bottom and not on the top.

From these considerations it would evidently be a most important object, if an inferior and otherwise worthless material, such as river gravel, could be so applied in roadmaking as to form a hard unyielding body, on which a covering of hard stone might be laid, without producing the same effects as if laid on a loose bed of the gravel. It is on this ground that I beg to recommend the use of concrete, composed of lime and river gravel, which being entirely divested of earthy matter, is probably one of the best materials that can be found for forming a strong and durable concrete. This kind of gravel has been used for the concrete placed in the foundations of many important buildings; amongst which I may mention particularly, the Penitentiary at Millbank, where a concrete foundation was laid by my father, the late Mr. John Hughes. From a long experience of the value of concrete, in this and other situations, I am persuaded that this material will form one of the best foundations for a road that has ever been tried. The nature of the lime, which composes so principal an ingredient in this concrete, rendering it quite impervious to water, no springs can break up through it, and this in damp situations is an extremely useful property. I have already alluded to the toughness of lime concrete; and I think I may add, that when this material has once become well set its hardness can scarcely be exceeded—it then becomes in fact perfect stone. As an instance in corroboration of this, I would mention, that before Mr. Telford determined on using concrete so extensively, in the foundations under some of those heavy breast-walls and warehouses at the St. Katherine's Docks, a specimen of the concrete, which I have already stated was some years before placed under the Penitentiary, was by authority allowed to be dug out. I saw a part of this specimen, and I never in my life witnessed any material resembling so nearly the Pudding-stone rock—a conglomerate which is always considered an exceedingly hard and perfect stone.

I should recommend for all the principal roads near London—after all the supplies of water from the sides as well as that falling on the road have been properly intercepted by longitudinal side drains and transverse ones leading into them, and occurring as often as the nature of the sub-soil may require—that a bed of lime concrete six inches in thickness, mixed as already described, be laid all over the breadth of the road; and that this bed be afterwards covered with six inches of the best flint or pit gravel that can be procured, in two courses of three inches at a time; or with, what in my opinion would be a much more lasting and serviceable material, four inches of broken granite stone: and I am convinced that a road so constructed, however bad the under stratum may be, will prove one of the hardest, most durable, and at the same time one of the cheapest roads ever formed in the neighbourhood of London.

I would here however suggest, that the surveyor (or whoever may have charge of a road so constructed) ought never to admit of the covering being worn down, so as to permit the concrete to be acted upon or in any manner disturbed; but as soon as the upper surface is worn down to within two inches, or at most to within one inch of the concrete, a new covering the same thickness as before should be immediately laid on.

It may not be considered very foreign to this subject to remark, that in gentlemen's parks, gardens, and pleasure-grounds, it is exceedingly difficult, if not impracticable, to make ornamental carriage roads or private walks by the old system of laying on loose gravel or broken stones; for whatever pains be taken in selecting the best kind of gravel and afterwards in forming and rolling, worms will find their way through and destroy it by depositing a portion of adhesive earth wherever they work to the surface; and these deposits are so numerous, particularly in the autumn and through the winter and spring of the year, that in the case of the carriage-roads, this earthy material first adheres to the rims of the wheels, and then again sticking to the gravel, tears up the whole surface to the entire destruction of the road. Garden walks from this cause frequently cannot be traversed with any pleasure—the dirt adheres to the feet and is so exceedingly unpleasant, that such roads and walks, instead of having a hard, clean, and smooth surface, become dirty and unsightly in the extreme. I would recommend in such places, that the roads and paths should uniformly he made with a concrete bottom of only a very few inches in thickness; say three inches for carriage roads and two inches for paths, and with a slight covering of binding gravel on the top. This system, I think, would effectually prevent the roads from being destroyed in the manner I have described; for independent of the antipathy which the worm, and I may add every description of insect, entertains against lime, and notwithstanding their capabilities of boring, they never could penetrate half an inch into the concrete. As an instance of the perseverance of worms, and of the mischiefs they sometimes occasion, I have myself, during a very dry hot summer, met with them in canal excavations, four feet below the surface in hard clay; and I have known them penetrate afterwards out of this depth and through three feet of clay puddle, thereby actually occasioning leakage in the canal.

CHAPTER VI.

On the Drainage of Roads.

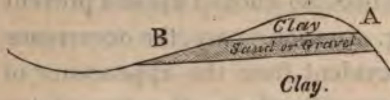
Of all the considerations which claim the attention of the practical roadmaker, that of complete and effective drainage is the most important, and generally the first which should be attended to. Although some roads are far more favourably situated than others with respect to the extent of artificial drainage required, it is quite certain that no road has any chance of becoming perfect unless the under stratum be rendered perfectly dry, either by natural or artificial means. The very best materials ever employed to form the crust of a road will be entirely thrown away, unless this very essential part of the work be first performed; and on the other hand, many very excellent roads owe their superiority almost entirely to the beneficial effects of good drainage. In the formation of a new road, or in improving those already made, no money is so well laid out as that expended in procuring perfect drainage; and what may at first sight appear to be an unnecessary outlay, will in the end be found the most economical application of capital that can be devised.

The particular kind of drainage required for roads must of course be determined by local and other circumstances; and it may now be advisable to consider some of the varieties of drainage to which these will give rise.

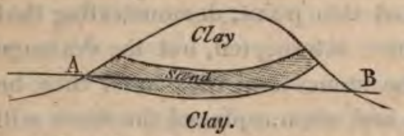
When a road is formed on a level with the ground on each side, there will seldom be found much difficulty in preventing the accumulation of water. In this case the road will not of course intersect any natural springs, which are often found exceedingly troublesome in other situations, and the only water to be carried off by the drains, is that falling on the surface of the road in the form of rain and snow. The most favourable circumstances under which a road can be placed for effecting this, are those in which a longitudinal inclination of not less than six or eight feet in a mile exists in the direction of the road. This fall of 1 in 880 or 1 in 660, although so nearly horizontal as to be scarcely perceptible, will be sufficient to carry off the water; but it is advisable if possible to obtain a greater fall, which will add very little to the draught of the road. In no case however should the fall of the road be less than six feet in a mile; and where a greater cannot be obtained the utmost attention must be paid to the state of the side drains, for unless these be kept well cleaned out, and unobstructed by weeds or other matters, it is obvious that the water will not pass off. If the bed of the road be formed with a regular convexity, as described in the second chapter, there will be no necessity for a centre longitudinal drain; nor after the road has become hardened will transverse mitre drains be required, because the water which may soak through the upper covering will naturally run off to the side drains. Should the water be found to stagnate in pools over any part of the side drains, the labourer in charge of the road should, as soon as he discovers this, drive the point of his pickaxe through the upper covering down to the rubble stones with which the drains are filled, when the water will find its way off the surface and make a ready escape by means of the side drain. As the field drains should always be lower than the side drains, and generally will be the lowest drainage that can be had for the road, it will be necessary, particularly where the longitudinal fall of the road is not considerable, to make frequent communications between the side drains and the outer field drains. These communications may be made at intervals of about forty or fifty yards, and may either consist of earthen pipes laid across under the mound and under the footpath or verge, or of brick drains, having an area or opening of about eighteen square inches. The field drains, placed on the outside of the mound or quickset bank, will of course be open drains, and will serve to drain the adjacent lands as well as the road itself. The side drains, however, formed within the limits of the road, should be filled with clean carefully selected rubble stones, not less in size than a cube of three inches nor larger than a cube of five inches, that is, containing from about thirty to one hundred cubical inches. These drains have sometimes a flat and sough tile placed in the bottom before the rubble stones are filled in. I should however recommend the following construction, namely, a flat tile in the bottom, the sides to be bricks on edge placed on the flat tile, and the top a tile similar to that in the bottom. I prefer bricks for the sides of the drain, because the sough tiles are so liable to breakage, an objection which does not apply to the flat tiles. These latter ought to be used for the bottom and top of the drain, because they occupy less space than bricks, and consequently leave more room for the rubble stones. The bricks may be placed on the bottom tile about four inches apart, so as to make the opening of the drain about eighteen square inches; and it will be advisable to leave a space of about a quarter of an inch at the end of each covering tile, to allow the water percolating through the rubble stones more freely to enter the brick drain. The side drains should always be formed at least a foot below the bed of the roadway, and they should never be made without either the sough and tile, or the brick drain above described; because, in addition to the facility thus given to the flowing of the water, the bricks and tiles prevent the rubble stones from being pressed, and sinking into the ground, as they would otherwise be likely to do.

Notwithstanding, however, all the precautions that can be taken, it will sometimes be found that the very best constructed drains become choked up and prevent the water from escaping. In such a case, the occurrence of which will soon be evident from the appearance of water on the surface immediately on the top of the drain, and sometimes on the road itself, the workmen should immediately proceed to open the suspected drain, a little lower down than where the water is observed to stop or break out upon the road. The drain will now appear dry at this point, demonstrating that the flow of water is here interrupted, but the drainage below is perfect. The stones and tiles must then be regularly cleaned out, and when replaced the drain will act as well as ever. Although a stoppage in one of the side drains, if allowed to continue, would soon destroy a good road, and particularly if it happen in wet weather, yet nothing is easier when once discovered than to effect the cure as above described.

The next case of drainage to be considered is, where the road has to be excavated below the natural ground surface, a situation in which the difficulties arising from the presence of water, and the necessity of preventing it from disturbing the bed of the road, are far more numerous than where the road is formed on a level with the natural surface. Almost every stratification with which we are acquainted, except clay and some of the very hard rocks, are capable of being penetrated by water, which percolates through them until it arrives at some low level where it can be discharged. It is impossible, however, from merely knowing the nature of a stratum to be cut through, to predict with anything like certainty whether it will be found to contain water. This depends so much upon its position with respect to other strata, that it is only upon a view of the situation, and an accurate knowledge of all the circumstances, that a correct judgment can be arrived at. For instance, a bed of sand or gravel, in the position shown in the annexed sketch, will



probably receive the water falling on the crown of the hill, which will then pass through it from A to B. where it may discharge into the valley. But if the bed of sand or gravel be found in the shape of a basin, as in *fig.* 2, it is obvious that all the water in the sand cannot pass off, because its flow is



impeded by the underlying bed of clay. The horizontal line A B, will represent the lowest level of drainage, and below this level we may expect to find the stratification full of water.

Although the relative positions of different strata are exceedingly variable, it will generally be found that any particular bed of porous gravel, sand, or chalk is wet or dry, according as the water which soaks into it in one place, is or is not dammed up by some stratum impervious to water, of which nature is almost every variety of clay. The deep excavations made for the canals, and more recently for some railways, afford remarkable instances of the truth and propriety of this distinction. For instance, the borings made on the line of the Brighton Railway, in the neighbourhood of Merstham and Oxtead, as well as the quarries which are extensively worked at various places along the Surrey chalk range, showed the chalk to be almost quite dry; whereas on the London and Birmingham Railway, in the neighbourhood of Tring, the chalk is entirely saturated with water, and although belonging to the same formation as the Surrey chalk, is extremely different in appearance and texture, being generally of a dingy cream colour, and very much shattered for a considerable depth. The reason of the difference is simply this, that in Surrey the gault brick earth, a strong tenacious clay which underlies the chalk in both cases at its outcrop, rises very little above the level of the lower chalk beds, and therefore the water percolating through the chalk is allowed to escape over the clay, which it accordingly does, forming several small streams flowing southward. But at Tring the gault rises to a considerable height above the level of the lower chalk beds, thereby damming back the water which remains in the chalk, at least as high as the level of a horizontal line drawn from the junction of the gault and chalk strata. Hence it is easy to account for the complete saturation of the chalk in this part of the country; and on the same grounds, we perceive the origin of the vast stream of water which was found to issue from the chalk excavation at Tring, as soon as the cutting was carried through the bed of gault, and the water thus provided with a channel of escape from the chalk.

In cutting through any porous stratification, where the water has been held back as at Tring, by an underlying bed which has also to be cut through, it is obvious that the excavation itself will serve to drain the porous stratum as low as the level of the road; and it will, therefore, only be necessary to make side drains of rather larger dimensions than in ordinary cases; and it will sometimes be found a very excellent and necessary expedient to lay down, along the centre of the cutting, a culvert or barrel drain of brick, into which communications should be made from the side drains, at intervals of twenty or thirty yards. The opening which the barrel drain should have will depend upon the quantity of water; but eighteen inches or two feet will be found sufficient in most cases; and the bottom of the barrel drain should always be sunk at least a foot lower than the bottom of the side drains, in order that the water from these may flow readily into the centre drain.

But perhaps the most difficult kind of excavations to drain, are those which so frequently occur through a stratification of clay alternating with beds of sand or gravel. A road cut to the depth of twenty or thirty feet may intersect a great number of these beds, from which the water will issue on the slopes, and if not properly guarded against, will produce the most injurious consequences. This is precisely the case with Highgate hill, particularly on the south side of the Archway: the water contained in the porous strata breaks out all over the slopes, carrying down portions of the loose running sand or gravel, and thus undermining large masses of earth, which consequently slip down into the road. Various expedients have been resorted to for the purpose of preserving the slopes, preventing slips, and protecting the road from the water breaking out on the slopes. At Highgate, and other places, wells or shafts, about four feet in diameter, have been sunk at several parts of the slopes, into which the water is allowed to drain, until it meets at the bottom with some porous bed of sand or loose gravel lower than the road, through which it can pass off away from the road and the slopes. This method, although very expensive, has seldom been found a very effectual remedy. In my opinion, a much better plan would be to form rubble drains along the face of the slopes, in order to intercept, if possible, all the water which breaks out, and conduct it into the side drains at the foot of the slopes. No general rule can be laid down for the direction and inclination which should be given to these drains; but they should be so projected as to intersect as many of the springs as possible, at the same time that a sufficient fall must be given to allow the water to pass freely along them. I have myself very commonly adopted this plan in canal and road excavations, particularly on the Union Canal, in Scotland, and at Forty-mile hill, on the London and Holyhead road, and have always found it succeed admirably. The drains should be filled with the same kind of rubble stones as already described for the road-side drains, and then covered with a thin layer of brushwood, over which earth or mould may be spread, so that no external appearance of drainage will be visible; and in almost all situations where water is found to break out on the surface of the slopes, this method of drainage will prove remarkably effective.

In all excavations I should make the drains at the foot of the slopes of greater depth and area than the side drains for a surface road; and it will also be necessary to form catchwater drains at the top of the slopes, to intercept the surface water, which would otherwise run down the slopes. The form and dimensions of these drains must in some degree depend upon the nature of the ground in which they are made. A width of three feet at top, and one foot six inches at bottom, and depth of two feet, will in most cases be found sufficient.

It would obviously be impossible, within any reasonable limits, to give rules for all cases where water is met with in road excavations; but I have no hesitation in asserting (as the result of a long course of practical and constant experience in matters of this kind,) that there is no case of drainage so difficult that some means cannot be found completely to overcome any obstacles that may arise; and rarely indeed is a tract of land so unsound, that it cannot by judicious management be rendered sufficiently solid and firm to bear the weight of any road which has to be made through it.

Instances frequently occur in which the adoption of some very simple expedient will effectually cause the water to disappear from a place where it is found troublesome. This may be done where water is found resting upon clay, beneath which exists any stratum of a porous nature; for if an opening be made through the clay, the water will usually escape, and filter through the inferior stratum. In this way many large tracts of land have been drained; and it will be advisable in all cases, before any expense be incurred in constructing drains or driving headings, to consider whether, from the nature of the sub-stratum, it is likely that a shaft sunk down a few feet will effect the purpose required.

The third and last case of drainage to be considered is, where the road has been raised on embankment above the natural surface of the ground. Here it is obvious, that the only danger to be apprehended from water is that which may be occasioned by rain or snow falling on the surface of the road. Should the water succeed in penetrating through the upper covering of the road, and sink into the body of the embankment, it will pass downwards without doing much mischief; but if the embankment be not composed of porous material, but consist of clay, which may perhaps have been much compressed, and as it were kneaded and puddled by the wheels of carts and waggons during the filling of the embankment, the water will not so readily sink into it, but be held up amongst the boxing or road metal. Under these circumstances, it is necessary that some kind of drainage should be provided. If the road have a longitudinal inclination, the drains to be formed in the road metal of the embankment should be of the kind called mitre drains; that is, they should not be formed across the road at right angles to its direction, but should be formed obliquely from the centre to the sides, in order that they may have a fall in the same direction as the road itself. The mitre drains are usually cut a foot wide and a foot deep below the bed of the road, and filled with clean stones, of the same description as those described for the side drains in cuttings. Mitre drains, however, are only necessary whilst the road metal or covering remains loose and unbound; because, when it has once become hard and solid, the water falling on the surface will not penetrate into it, but run off towards the sides: hence I should never advise the formation of these drains, except where heavy rains are expected, before the road metal can have time to set and harden; and even then, as before stated, they are only necessary on embankments formed of clay, which has been rendered impervious to water. I should think it possible, in all cases, to lay on the road metalling even on a clay embankment, and to cause it to set and become hard before it can be injured by rain; and whenever this can be done the mitre drains may be dispensed with. Suppose now the road surface to be formed hard and solid, so that the water which falls on it will not sink in, but run off towards the sides; if the road has been made without footpath or verge, the water will of course run off the top of the embankment and down the sides of the slopes; but if on opposite sides of the carriage-way a footpath and verge have been formed, drains must be laid under these at intervals, to conduct the water from the sides of the road on to the slopes. These drains may be similar to those described for the road on a level with the ground surface, and may be placed at the same interval apart, namely, forty or fifty yards. From the points where these drains open on the slopes, it is an excellent plan to form paved channels directly down the slopes, in order to preserve the latter, and prevent the water from spreading over their surface, and sinking into the embankment. These paved channels may be formed with any rough pitching stones, and should be made about two feet wide, with a concavity or dish in the centre of about four inches; and to add to the finished appearance of the slopes, the sides of these channels may be defined by a row of grass sods, laid with the green sward uppermost.

CHAPTER VII.

On the Means of comparing different Roads, and of estimating the Effect of Inclinations, and the other Causes producing resistance to Motion.

No pretence is here made of being able to afford the engineer any information in the practice of a part of his profession, which is commonly executed with so much ability and judgment, as the laying down and tracing through a district of country the line of a new road. It will obviously be travelling beyond the limits in view, to enter upon the general engineering considerations which may present themselves, to determine the merits and defects of particular new lines, and finally to turn the balance of opinion in favour of that one which is found, upon investigation, to possess the most decisive merits. These considerations are, to a certain extent, similar and mutually applicable in the several cases of canals, railways, and common roads. They involve the necessity of land surveys, from which the features of the country, in respect of property and population, must be accurately known and delineated. Surveys, also, of levels are absolutely necessary, that sections of the country may be made in various directions, to show the heights of summits and depths of valleys to be intersected, and generally to determine the nature of the inclinations of which the new road is to consist. The judgment of the engineer is formed with these data before him; and in all works of importance that judgment ought to be based upon a thorough practical experience, aided by a perfect knowledge and deliberate consideration of all the various circumstances in which the new work is to be placed, or which may be brought to bear upon its future position. The attempt to lay down any general rules on a subject capable of such extended ramification, would probably fail to convey much useful information; but with a view to the comparison of roads already existing, and in order to arrive at some simple means of appreciating the force of draught required on different roads, and on different parts of the same road, it may be useful to consider the effects of gravity and friction in producing increase or diminution of the draught.

The former of these, namely gravity, is a force very easily estimated. On a level plane or horizontal road, the entire weight of any carriage is supported by the road itself, and therefore the moving power is not taxed to support any of the weight; hence in this case there is no resistance whatever by reason of gravity, the only retarding force being that of friction, or the resistance to motion occasioned by the rugged uneven surface of the road. On a plane inclined to the horizon, the effect, with respect to the power of traction required, is the same as if the weight be only partially supported by the road. The amount so supported is equal to the whole weight, *minus* that portion of it denoted by the inclination of the plane; thus on an inclination of 1 in 30, expressed by the fraction $\frac{1}{30}$, the amount $\frac{29}{30}$ of the weight is supported by the road, and the remaining $\frac{1}{30}$ has to be supported by the moving power. The consequence is that, calling the natural sine of the inclination of any plane the quotient of the height divided by the length, in the case of a weight *ascending* the plane, the force of traction required is equal to the friction *increased* by the product of the weight multiplied by the natural sine of the inclination; and in the case of a weight *descending,* the force of traction required is equal to the friction *diminished* by the same product.

The friction of a carriage moving on a road is expressed by that weight which, being connected with it, suspended over a pulley, and allowed freely to descend, will drag the carriage along a level road. That weight is usually stated which in this way is capable of dragging a ton; and various experiments have been made to determine the amount of this weight, or the friction of a ton on different kinds of road. Sir Henry Parnell, in his Treatise on Roads, gives the following table:

Table of Friction.	In lbs. per ton.
On a well made pavement	33
On a broken stone surface, or old flint road . . .	65
On a gravel road	147
On a broken stone road, with a rough pavement foundation	46
On a broken stone surface upon a bottoming of concrete, formed of Parker's cement and gravel . .	46

These results have been principally derived from experiments with Mr. M'Neil's dynamometer, and must be understood as only applicable to very slow velocities. On all surfaces where the friction is considerable, the amount of this retarding force increases very much as the velocity of the moving body increases; hence in all experiments on this subject, the rate of travelling at which the friction is taken, should be particularly noticed, otherwise the experiment can be of no utility.

A very good practical method of determining the friction is to place a carriage, waggon, cart, or other vehicle mounted on wheels, and with axles well greased, upon a sloping road, and ascertain the inclination on which the vehicle will just move forward by the force of its own gravity. At this inclination, whatever it may be, the force of gravity is of course exactly equal to the friction, because the former is just capable of overcoming the latter resistance, and causing the body to move. The inclination at which this effect takes place is called the angle of repose, or the angle of friction. Now the force of gravity is easily determined, being, as before stated, equal to the weight of the body multiplied by the *inclination* of the plane; and the friction being, in the case supposed, exactly the same as the force of gravity, is of course determined by the same means. For example: if it be found that a carriage will just begin to move downwards on an inclination of 1 in 30, the friction of a ton weight on a level road of the same kind will be equal to $2240 \times \frac{1}{30} = \frac{2240}{30} = 74\frac{2}{3}$ lbs. The amount of friction thus found ought to correspond with that which would be indicated by the dynamometer, because in both cases the rate of motion would be very slow. As the inclination of a road is usually expressed by a fraction of which the numerator is unity, this fraction being also called the natural sine of the angle of inclination, the rule for finding the force of gravity, by multiplying the weight by the fraction expressing the inclination of the plane, is of course the same thing as to divide the weight by the length of the plane corresponding to a rise of 1. Hence putting the weight = W, and the inclination of the plane = $\frac{1}{r}$, the simple formula $\frac{W}{r}$ will express the force of gravity of the weight W. This amount $\frac{W}{r}$ has to be added to the friction in the case of a weight being drawn up the plane, and deducted from it in the case of a weight descending the plane. Probably, however, the most useful form in which to exhibit the effect of various inclinations with respect to the power of traction required, will be to determine the weights which, on a level road of the same kind, will require exactly the same power of traction. This is extremely simple: for if F be the friction of a given weight W, and $\frac{W}{r}$ as before be the force of gravity, we have the whole resisting force $= F + \frac{W}{r}$ for the ascending plane, and $F - \frac{W}{r}$ for the descending plane. Then to find the weight which the power $F + \frac{W}{r}$ is capable of moving on a level plane, we have this proportion, $F : W :: F + \frac{W}{r} : W'$ the weight required, hence $W + \frac{W^2}{rF} = W'$. In the same way for a descending plane, we have $F : W :: F - \frac{W}{r} : W'$; hence $W - \frac{W^2}{rF} = W'$, the weight which can be moved on a level with the same exertion of force as that required to move the weight W on a descending plane, whose inclination is $\frac{1}{r}$. On this principle the following table has been constructed; but it must be observed, that the value of F, which in the table is assumed at 112 lbs., must be determined for any particular road on which the resistance has to be calculated. For roads where the friction either very much exceeds or falls short of this amount, the last column only will be of use in saving the labour of calculation; because this shows the power required to overcome the force of gravity alone, independent of friction, on the several inclinations from 1 in 300 up to 1 in 5.

Table of Resistances and Equivalent Loads, where the Friction is $= \frac{W}{20}$ or 112 lbs. per Ton.

Rate of Inclination.	Resistance of one ton, or power required to draw one ton when the friction is $= \frac{W}{20}$ or 112 lbs. per ton.		Equivalent load on the level, or load which requires the same power of draught as one ton.		Resistance arising from gravity alone, or value of the fraction $\frac{2240}{r}$
	On the ascending plane.	On the descending plane.	On the ascending plane.	On the descending plane.	
	lbs.	lbs.	Ton. lbs.	Ton. lbs.	lbs.
1 in 300	119·47	104·53	1. 149·3	0. 2090·7	7·4667
,, 295	119·59	104·41	1. 151·9	0. 2088·1	7·5932
,, 290	119·72	104·28	1. 154·5	0. 2085·5	7·7241
,, 285	119·86	104·14	1. 157·2	0. 2082·8	7·8596
,, 280	120·00	104·00	1. 160·0	0. 2080·0	8·0000
,, 275	120·15	103·85	1. 162·9	0. 2077·1	8·1454
,, 270	120·30	103·70	1. 165·9	0. 2074·1	8·2963
,, 265	120·45	103·55	1. 169·0	0. 2071·0	8·4528
,, 260	120·62	103·38	1. 172·3	0. 2067·7	8·6154
,, 255	120·78	103·22	1. 175·7	0. 2064·3	8·7843
,, 250	120·96	103·04	1. 179·2	0. 2060·8	8·9600
,, 245	121·14	102·86	1. 182·8	0. 2057·2	9·1428
,, 240	121·33	102·67	1. 186·7	0. 2053·3	9·3333
,, 235	121·53	102·47	1. 190·6	0. 2049·4	9·5319
,, 230	121·74	102·26	1. 194·8	0. 2045·2	9·7391
,, 225	121·96	102·04	1. 199·1	0. 2040·9	9·9555
,, 220	122·18	101·82	1. 203·6	0. 2036·4	10·1818
,, 215	122·42	101·58	1. 208·4	0. 2031·6	10·4186
,, 210	122·67	101·33	1. 213·3	0. 2026·7	10·6667
,, 205	122·93	101·07	1. 218·5	0. 2021·5	10·9268
,, 200	123·20	100·80	1. 224·0	0. 2016·0	11·2000
,, 195	123·49	100·51	1. 229·7	0. 2010·3	11·4872
,, 190	123·79	100·21	1. 235·8	0. 2004·2	11·7895
,, 185	124·11	99·89	1. 242·2	0. 1997·8	12·1081
,, 180	124·44	99·56	1. 248·9	0. 1991·1	12·4444
,, 175	124·80	99·20	1. 256·0	0. 1984·0	12·8000
,, 170	125·18	98·82	1. 263·5	0. 1976·5	13·1765
,, 165	125·58	98·42	1. 271·5	0. 1968·5	13·5758
,, 160	126·00	98·00	1. 280·0	0. 1960·0	14·0000
,, 155	126·45	97·55	1. 289·0	0. 1951·0	14·4516
,, 150	126·93	97·07	1. 298·7	0. 1941·3	14·9333
,, 145	127·45	96·55	1. 309·0	0. 1931·0	15·4483
,, 140	128·00	96·00	1. 320·0	0. 1920·0	16·0000
,, 135	128·59	95·41	1. 331·8	0. 1908·2	16·5926
,, 130	129·23	94·77	1. 344·6	0. 1895·4	17·2308
,, 125	129·92	94·08	1. 358·4	0. 1881·6	17·9200
,, 120	130·67	93·33	1. 373·3	0. 1866·7	18·6667
,, 115	131·48	92·52	1. 389·6	0. 1850·4	19·4783
,, 110	132·36	91·64	1. 407·3	0. 1832·7	20·3636
,, 105	133·33	90·67	1. 426·7	0. 1813·3	21·3333

Table of Resistances and Equivalent Loads—continued.

Rate of Inclination.	Resistance of one ton, or power required to draw one ton when the friction is $= \frac{w}{20}$ or 112 lbs. per ton.		Equivalent load on the level, or load which requires the same power of daught as one ton.		Resistance arising from gravity alone, or value of the fraction $\frac{2240}{r}$
	On the ascending plane.	On the descending plane.	On the ascending plane.	On the descending plane.	
	lbs.	lbs.	Ton. lbs.	Ton. lbs.	lbs.
1 in 100	134·40	89·60	1. 448·0	0. 1792·0	22·4000
,, 95	135·58	88·42	1. 471·6	0. 1768·4	23·5789
,, 90	136·89	87·11	1. 497·8	0. 1742·2	24·8889
,, 85	138·35	85·65	1. 527·1	0. 1712·9	26·3529
,, 80	140·00	84·00	1. 560·0	0. 1680·0	28·0000
,, 75	141·87	82·13	1. 597·3	0. 1642·7	29·8667
,, 70	144·00	80·00	1. 640·0	0. 1600·0	32·0000
,, 65	146·46	77·54	1. 689·2	0. 1550·8	34·4615
,, 60	149·33	74·67	1. 746·7	0. 1493·3	37·3333
,, 55	152·73	71·27	1. 814·5	0. 1425·5	40·7273
,, 50	156·80	67·20	1. 896·0	0. 1344·0	44·8000
,, 45	161·78	62·22	1. 995·6	0. 1244·4	49·7778
,, 40	168·00	56·00	1. 1120·0	0. 1120·0	56·0000
,, 35	176·00	48·00	1. 1280·0	0. 960·0	64·0000
,, 30	186·67	37·33	1. 1493·3	0. 746·7	74·6667
,, 29	189·24	34·76	1. 1544·8	0. 685·2	77·2414
,, 28	192·00	32·00	1. 1600·0	0. 640·0	80·0000
,, 27	194·96	29·04	1. 1659·3	0. 580·7	82·9630
,, 26	198·15	25·85	1. 1723·1	0. 516·9	86·1538
,, 25	201·60	22·40	1. 1792·0	0. 448·0	89·6000
,, 24	205·33	18·67	1. 1866·7	0. 373·3	93·3333
,, 23	209·39	14·61	1. 1947·8	0. 292·2	97·3913
,, 22	213·82	10·18	1. 2036·4	0. 203·6	101·8182
,, 21	218·67	5·33	1. 2133·3	0. 106·7	106·6667
,, 20	224·00	0	2. 000·0	0	112·0000
,, 19	229·89	,,	2. 117·9	,,	117·8947
,, 18	236·44	,,	2. 248·9	,,	124·4444
,, 17	243·76	,,	2. 395·3	,,	131·7647
,, 16	252·00	,,	2. 560·0	,,	140·0000
,, 15	261·33	,,	2. 746·7	,,	149·3333
,, 14	272·00	,,	2. 960·0	,,	160·0000
,, 13	284·31	,,	2. 1206·2	,,	172·3077
,, 12	298·67	,,	2. 1493·3	,,	186·6667
,, 11	315·64	,,	2. 1832·7	,,	203·6364
,, 10	336·00	,,	3. 000·0	,,	224·0000
,, 9	360·89	,,	3. 491·8	,,	248·8889
,, 8	392·00	,,	3. 1120·0	,,	280·0000
,, 7	432·00	,,	3. 1920·0	,,	320·0000
,, 6	485·33	,,	4. 746·7	,,	373·3333
,, 5	560·00	[illegible]	5. 000·0	,,	448·0000

The construction and use of this table are so simple as to require very little explanation. The 2nd and 3rd columns show the actual amount of power required to drag a weight of one ton, on the several ascending and descending planes, of which the inclinations are given in the 1st column. These amounts of power being known, the 4th and 5th columns, showing the load which can be drawn on a level, by the same power as that necessary to draw a ton respectively up and down the several inclinations in the 1st column, are easily calculated by means of the proportion already mentioned. Where the load has to be drawn *up* the inclination, it is evident that more power must be exerted than is necessary to draw the same load on a level; hence the amounts of power in the 2nd column are all *more* than 112 lbs., because this is the power required to draw a ton on the level. Again, where the load is *descending* the inclination, a less amount of power is necessary than on a level; hence the amounts in the 3rd column are all *less* than 112 lbs. It follows also, from the nature of the formula $F \mp \frac{W}{r}$, by which these amounts have been calculated, that on any given inclination the amount of power required to ascend, the amount required on a level, and the amount required to descend the given inclination, are three quantities having a common difference, and therefore in arithmetical progression. This is further evident, in considering that the excess required to ascend is equal to the diminished quantity sufficient in descending. And since the equivalent loads which can be drawn on a level are proportional to the power expended, the same property obtains with regard to them:—for example, the load which can be drawn on a level with the same power required to draw a ton weight *up* any given inclination, and the load which can be drawn on a level with the same power required to draw the ton weight *down* the given inclination, are the extremes of an arithmetical progression, of which *one ton* is the mean or middle term. These properties may be shortly expressed algebraically: thus, let P be the power required to draw the load W up any given inclination, and p the power to draw the same load down the inclination; also, let F, as before, be the friction of the load W on a level, then we have $\frac{P+p}{2} = F$. Further, let L be the equivalent load on a level for an ascending plane, and l the equivalent load for a descending plane of the same inclination, then $\frac{L+l}{2} = W$.

It is obvious, if we know by experiment the amounts of power P and p required to draw any weight respectively up and down any inclination, that we can at once determine the friction of that weight, or the power required to draw it on a level, and also the rate of inclination for which the amounts P and p have been ascertained. Without supposing that this method of finding the inclinations of a road, will ever supersede the more accurate method of levelling for that purpose, it may yet often be found useful to approximate in this way. We have already seen that $\frac{P+p}{2} = F$; and since P is the whole power of draught up the plane, and F is that part of the whole power which arises from friction, it is evident that $P - F$ is equal to the resistance arising from the force of gravity on the inclination. Now the force of gravity is also equal to $\frac{W}{r}$; hence putting these two expressions equal to each other, we have only to find from the equation $P - F = \frac{W}{r}$, in which all the quantities are given except r, the value of this unknown quantity expressing the inclination of the plane. Solving then the above equation, we have $r(P-F) = W$, and $\frac{W}{P-F} = r$, the rate of inclination. An example of this may be taken from the table:—Suppose the amounts of power required to draw a ton weight up and down a certain inclination be respectively 128 and 96 lbs. then $\frac{128+96}{2} = \frac{224}{2} = 112 = F$ the friction as in the table. And $\frac{2240}{128-112} = \frac{2240}{16} = 140 = r$; that is, the inclination of the plane for which these amounts of power have been determined, is 1 in 140, as in the table. It is easy when the inclination of a plane is given to ascertain the difference of level between any two points on its surface, provided we know the direct distance between them measured in the line of the plane: thus, if an inclination rise 1 in r, it is evident that in each unit of length the rise will be $\frac{1}{r}$; hence if we divide any given length on the plane by the denominator of the fraction expressing the rate of inclination, the quotient will be the difference of level of the two points at the extremities of that length.

In all roads there is a certain angle of inclination on which it will require no power to cause a weight to descend. This has been already mentioned under the name of the angle of friction; and it follows from the nature of the relation existing on every plane, between the power required to descend and that required to ascend, that where the power to descend is equal to zero, or where $p = 0$, the power required to ascend is equal to $2\ F$ or double the friction. But where the value of p becomes negative or less than *nothing*, that is, where $\frac{W}{r}$ is greater than F, the amount of power required on the descent being also less than *nothing*, has no longer to be calculated. In fact, where the plane is of greater inclination than the angle of friction, the load in descending acquires an accelerating force, which if not checked would urge it downwards too rapidly. Hence it is usual in such a case to increase the amount of retarding force actually occasioned by friction, and for this purpose the break or skid is applied—the inclination at which it becomes necessary to use the break, or in other words to lock the wheel, being properly speaking the angle of friction. It is obvious that this angle is not the same for all kinds of road, since it depends entirely on the amount of the friction itself; thus in the table where the friction of one ton is taken at $\frac{1}{20}$, or 112 lbs., the angle of friction is that which is made with the horizon by a plane whose inclination is 1 in 20; and in general terms, if F be the amount of friction for any weight W, the inclination of the plane forming the angle of friction, will be $\frac{F}{W}$.

In order to illustrate the effect of steep inclinations, it may be useful again to refer to the preceding table, where we find for instance that the load on a level, equivalent to one ton ascending an inclination of 1 in 20, is just double or two tons; and if the road become as steep as 1 in 10, the equivalent load is three times as great or three tons; thus, the inclination of 1 in 10 requires 50 per cent. more power than the inclination of 1 in 20. Again, the inclination of 1 in 60 requires a power equivalent to that which would draw 1 ton 747 lbs. on a level; and as this equivalent load bears the same proportion to two tons as this latter load bears to three tons, it is evident that the inclination of 1 in 10 has the same relation to 1 in 20 as this latter has to 1 in 60. Next, as to the actual differences of draught, it appears, that if a horse can just draw one ton upon a level road, it will require two horses to ascend with this weight an inclination of 1 in 20, and three horses to ascend an inclination of 1 in 10. Hence the extremes of power required, within the short range of 1 in 10 and 1 in 20, present as wide a difference as in the long range between 1 in 10 and a perfectly horizontal plane.

When it is necessary to calculate the draught required on a road where the friction has been determined at any other amount than 112 lbs., the 6th or last column of the table must be employed. Thus, if the friction on a road should be found, for example, to be 150 lbs. per ton, and it be necessary to find the power of draught required on an inclination of 1 in 80 :—Take from the table the amount in the 6th column opposite to 1 in 80, this amount which is 28 lbs. being the force of gravity alone. Then $150 + 28 = 178$ lbs. is the whole power required to draw a ton up the inclination, and $150 - 28 = 122$ lbs. is the amount required to draw the weight down the inclination. Further, $\frac{2240 \times 178}{150} =$ 2658 lbs. the weight which can be drawn on a level by the power of 178 lbs., and $\frac{2240 \times 122}{150} = 1822$ lbs. the weight which can be drawn on a level by the power of 122 lbs. The 6th column of the table will also be useful if we wish to ascertain the angle of friction corresponding to different amounts of draught on roads. For example, if on any road the friction or resistance on a level be equal to 80 lbs. per ton, the angle of friction for this road will be 1 in 28. And so of any other amounts in the 6th column, the rates of inclination opposite to them in the first column being respectively the numbers which express the corresponding angles of friction.

In the preceding exposition of the methods of estimating the forces of friction and gravity on different roads, it must be understood that these forces express only the power required to set in motion a given weight under the circumstances for which that power is calculated. In order to know the whole power required to draw a given weight along any length of plane, inclined or horizontal, we must multiply the force required to move it by the length of the plane itself, and the product will be the whole power required. This must be evident if we consider that the force required to set in motion any load placed on a certain plane, is that weight which hanging over a pulley will just cause the load to move; and if we conceive the load to advance on the plane any given length, this advance must be produced by a corresponding and equal descent of the attached weight. Hence, if a power P be required to move a given load on a plane 500 feet long, the whole force required to move the load from one end of the plane to the other is $= 500\,P$; that is, the force is equal to the weight P raised 500 feet high, or which is the same thing, to the weight $500\,P$ raised 1 foot high.

In applying the principles which have now been laid down, to determine the comparative merits of two or more lines of road, it will be necessary to compute for each inclination the actual power required to ascend and descend with a given weight, and it would seem at first sight, that the aggregate or total of these amounts would afford an expression by which to indicate the comparative merit of any line of road. It will be found, however, in following out the consequences of some of the propositions laid down in the preceding pages, that this expression, although perfectly accurate, as containing the actual amounts of force to be exerted on each plane throughout the road, will yet fail in a remarkable degree to establish the absolute superiority of one line over another, although the power on the former may be unquestionably less in amount than that required on the latter. In illustration of this exception, it will be necessary to revert to that relation subsisting between the three amounts of power exerted in ascending any given plane, in moving on a level, and in descending the given plane. It has already been observed, that these three quantities are in arithmetical progression, and the expression already made use of, namely, $\frac{P+p}{2} = F$, exhibits the following result; that the half sum of the amounts of power required to ascend and descend a given inclination, is exactly equal to the power required to move over a level plane equal in length to the inclination itself. The same proposition may also be expressed in other words, thus:—that *to ascend and descend a given inclination, requires the same power as to travel backwards and forwards over a level plane equal in length to the inclination.*

Before proceeding to the consequences of this doctrine it is necessary to notice, that it no longer holds true when the angle of inclination of the given plane exceeds the angle of friction for the road in question. It is evident that on all planes where the carriages will descend by the force of their own gravity, the expression above used is no longer correct; because, whatever be the inclination of the plane the only value of p is 0; and as P increases with each increase in the rate of inclination, it will at once be obvious, that to ascend and descend any plane forming with the horizon a greater angle than the angle of friction, requires more power than to travel backward and forward the same distance on a level plane. It will therefore be understood, with respect to the proposition establishing that an equal amount of power is required to travel up and down an inclination, and to travel double the length of the inclination on a level, that this applies only to planes of less inclination than that formed by the angle of friction.

We are now to consider the extent to which an expression of power leading to such a result, may be used as a means of comparing the merits of different roads. With this view we are to bear in mind the nature of the power which has to be employed, in overcoming the several resistances that may be determined by calculation. This power on the common roads is generally confined to the labour of horses; and when, with reference to this species of power, we assert the proposition as to the equality of force required, it becomes perhaps more irreconcileable with the knowledge derived from every-day experience, than when applied to any other description of power whatever. Thus, to assert that the labour of travelling along a mile of road on which is a summit 100 feet high requires no more power than to travel over a mile of level road, appears very inconsistent with generally received opinions; and yet this assertion is strictly in accordance with the general proposition; because, if the summit be placed half way the inclination on each side will be 1 in 26, which for an amount of friction $= \frac{1}{20}$ is a flatter inclination than the angle of friction. It will therefore be necessary to introduce into the expression for the actual mechanical force to be exerted, some modifications, in order to render the results more nearly coincident with those of known experience. In the first place, the horse ascending an inclination has to raise his own weight in addition to the load, and the power thus expended must of course be added to that necessary for the load. Again, in descending, it is probable that it requires just as much exertion to transport his weight as on a level. Now the additional power required to carry the weight of a horse up an inclination, is evidently equal to his whole weight multiplied by the height of the inclination; and in fact, the power required for this purpose is in no respect different except in amount from that required to raise the load drawn by the horse. Hence, it will be proper in determining the resistance of a load to be drawn up any inclination, to consider the weight of the horse itself as a part of the load. This, if we assume the weight of a horse at 10 cwt., or half a ton, and suppose the load to be drawn is one ton, the amounts expressing in the table the resistances arising from gravity must be increased 50 per cent. for the

CHAPTER VIII.

On the Method of Estimating the Prices of Earth-work, and other kinds of Labour necessary in the Improvement and Repair of Roads.

THE particular circumstances of different localities exercise so much influence on the value of most descriptions of labour and materials necessary in road-making, that any thing like a general scale, comprising all kinds of labour, would be entirely out of the question, and probably quite inapplicable to every other than the particular district from which the data for its construction had been derived. This remark applies to the prices of digging, screening, breaking, washing, and otherwise preparing gravel; the prices of quarrying and carting stone, and forming the pitching in the bed of the road; also to the prices of fencing and ditching, constructing drains, footpaths, &c. All these kinds of labour vary in value, and the price to be paid for them, according to the condition of the labouring population, and their usual employers the farmers, and according to other circumstances which it will not be necessary here to enter upon.

In the improvement of roads upon an extensive scale, however, the preceding kinds of labour are all of minor importance as compared with that of excavating earth and filling it into embankments, in order, by thus lowering the hills and raising the valleys, to produce more gradual inclinations, and consequently a better kind of road. The value of this description of work (although, as may naturally be supposed, it forms a study of the greatest consequence to all those engaged in the management of roads,) is generally very little understood; and many and serious are the evils which have fallen upon the heads of trustees and surveyors from the want of practical knowledge on this subject. The obvious data from which the value of excavating earth should be computed, consist of the amount or quantity of the material which can be excavated by a given quantity of labour; and thus, if the value of this labour be known, we obtain at once the price of the work done, and may estimate from such groundwork the value of any other quantity, great or small.

These data of course can only be derived, in the first instance, from actual practical observation and experience on many and different works; but being once known, they become of great importance in the business of estimating the future cost of any works of the same kind.

The workmen employed in earth excavations are always divided into two classes, getters and fillers; the former employed in undermining, driving down by piles, and breaking to pieces with pickaxes the earth to be loaded into the carts or barrows by the fillers. It will be seen, in the course of the following observations, that in determining the price of earthwork, it is very important to obtain an accurate knowledge of the proportion in which these two classes, getters and fillers, are required to be employed.

Where any considerable quantity of earth has to be removed, the modern practice is to lay down iron rails for the waggons to travel on from the excavation to the embankment. It is found in such cases to be the interest of the contractor, that the roads from the excavation to the teaming-places should be constructed in a very perfect manner, and that heavy waggons of the most durable make should be employed. We may readily conceive the extensive establishment of roads and waggons necessary in some of the gigantic works of the great lines of railway, on which it is by no means uncommon to meet with single hills to be lowered and filled into a valley containing upwards of a million of cubic yards, with a distance of carriage varying from one to five miles. In the transport of such vast masses of earth for such considerable distances, the roads cannot be too well constructed; and in the end it will generally be found that capital expended in this way produces a very satisfactory return.

A wide difference exists, however, between the vast earth-works of the railways and those which are usually necessary in road formations, where the quantity of earth to be excavated from any one place seldom exceeds four or five thousand yards, and scarcely ever amounts to twenty thousand. In works of a nature comparatively so trifling, the expense of heavy waggons, and the rails and sleepers necessary to carry them, would on no account be justified.

I shall therefore confine myself to those methods of removing earth which are more particularly adapted for small quantities and short distances. Of all the implements employed for this purpose, the common earth wheelbarrow is perhaps the most convenient, not only from the ease with which it can be loaded, but from the great facility with which it can be brought to the very spot where it has to be filled or emptied. By simply turning the direction of the spurring, which is generally a 10 or 14 feet plank, without altering the direction of the main line of wheeling planks, the barrows can be filled at the face of the cutting, or emptied at the teaming-place at the precise spot required. But with waggons and rails the case is very different; for any alteration at either end of the road requires generally a considerable length of rails to be taken up and replaced, an operation which is found very tedious and troublesome, and which contributes very much to increase the expense of the teaming. Where waggons are employed, this part of the work seldom costs less than 1*d*. per cube yard; and in winter and wet weather, I have frequently known the teaming of adhesive clays, and some descriptions of wet sand, to cost from three-halfpence to twopence per cube yard.

The advantage of filling into barrows instead of waggons I estimate, from practical experience, to be equal to the removal of the earth, after filling it, to a distance of one stage of wheeling; or in other words, the same set of fillers in the same material will fill and move with barrows, to a distance of one stage, for the same price that they can fill alone into the waggons. This arises from the extra lift the workman must make to raise his load over the side of the waggon: and not only is it necessary in this way to carry it upwards a much greater distance, but the moment the workman raises himself to a perpendicular position, he works to great disadvantage; for it requires much more strength to raise the same weight when he once elevates his position, than whilst he remained in a leaning or stooping attitude. In the latter position the weight of his body powerfully assists in bringing up the load, but in the upright posture he has nothing to assist him but his arms. In filling into a waggon also, the constant strain upon his loins is so excessive, that he cannot take up at any one time, and deposit in one of the high waggons, more than two-thirds of the load that he could raise and fill with ease into a barrow. It would seem that these causes very satisfactorily account for the difference already mentioned between the two kinds of filling. The quantity of earth, however, which the barrow is capable of holding being very small, it is obvious that this mode of removal would become tedious and expensive for long distances; and it is found accordingly, that the barrow cannot be economically employed in the removal of earth which has to be taken more than sixty yards from the face of the cutting. A stage of running with barrows is twenty yards, and the price per stage 1*d.* per yard: it is however usual for the principal contractor to bargain with his gangsman or foreman at a price per yard, for any distance not exceeding twenty yards from the face of the cutting, and at the rate of 1*d.* per yard extra for every stage of twenty yards beyond the first stage; thus stuff requiring one getter to three fillers would cost 6*d.* per yard. It must be here observed, that one man can wheel to the distance of twenty yards for three fillers, or from forty to fifty yards per day; thus the cost of 6*d.* per yard is incurred, filling 3*d.*, getting 1*d.*, wheeling two extra stages 2*d.* At this rate of pay six men will remove about forty-two yards, and earn for their labour 3*s.* 6*d.* per day; each filler filling fourteen yards, and removing it from the face to the distance, as it increases, from one to twenty yards.

With reference to the best description of cart or waggon to be employed, when it becomes necessary to abandon the use of the barrow, there are of course as many different opinions as there are varieties of form and figure in the vehicles themselves. I have myself devoted much attention to this subject, and having used many different kinds, am enabled to point out one or two which possess nearly equal advantages in point of convenience and economy. One of the best with which I am acquainted is the three-wheeled cart. These can be taken in and out of the cutting, either backwards or forwards: they stand low, and are therefore easily loaded, and have a decided advantage over the common two-wheeled cart, and the Scotch one-horse cope-cart, on account of the ease and expedition with which they can be dispatched from the face of the cutting and from the teaming-place.

A great deal of time is always lost with the common two-wheeled carts, because the horse must wait during the process of loading and unloading; but with the three-wheeled cart the horse draws with chains, which are hooked on to the loaded waggon, which, on coming to the face of the cutting, is not detained there a moment longer than is occupied by this operation: and the same thing takes place at the teaming-head, where the horse, as soon as he arrives with a loaded cart, is hooked on to the one which he had left there the last trip, and returns as quickly as he can to the face of the cutting. In this way the three-wheeled carts work remarkably well, and with great regularity, particularly in fine weather, and good dry shifting earth. Although in wet weather, and with clayey earth to remove, they cannot be so strongly recommended, yet there are so many times and places where these carts can be employed to advantage, that they ought, if possible, in all earth-works to be in readiness for the occasion which may call them into use. In forming embankments, where it is important that rapid consolidation should take place, the three-wheeled carts are extremely valuable, because they can be teamed over a two feet face almost as conveniently as over a heavier and deeper lift; and the embankment may thus be formed in shallow layers, over which the constant travelling of the horses and carts produces the effect of consolidation, almost simultaneously with the completion of the embankment.

Earth which has been filled in this way is also more likely to stand firm, and much less liable to slips than that which has been placed in embankment in a less compressed state. Three-wheeled carts may be economically used in removing earth to a distance of about half a mile, or say 900 yards; and the cost of carriage may be taken at about 1*d*. for every 100 yards, where the distance of removal is about 300 yards.

I have observed that a good horse will make from forty-five to fifty journeys per day, drawing on an average 18 cube feet at a time; or in other words, a good horse will remove from 30 to 33 cube yards per day to a distance of 300 yards from the face to the teaming, or unloading end: where, however, the length of carriage exceeds this distance, and the loading and unloading become less frequent, the expense of carriage will be proportionably diminished. In the same ratio also the cost will be augmented for shorter distances than 300 yards, where of course the interruptions of loading and unloading are more frequent.

Another description of cart which I have extensively employed in removing small hills, has been found very convenient both for loading and teaming. This is termed a go-cart, and has sometimes been run by men upon planks; but as they are very apt to get off the tracks, and destroy the planks in an extraordinary manner, I do not recommend their use in this way. The go-cart has two long trams or shafts, to the end of which the horse may be hooked, and is supported by two legs in front, which preserve the cart when at rest in a horizontal position. When the cart is in motion, the driver travels between the shafts, holding them up to clear the legs from touching the ground, and prevent the cart from tipping over, as it would be likely to do with only one point of support.

I prefer these carts made large and very strong, with substantial wheels: they will carry on a good road from 18 to 23 cube feet of earth, and with this load the horse will travel at a fair speed. These carts possess all the requisites of the three-wheeled kind, both in the facility with which they can be loaded and unloaded without detention of the horse, and in their capability of being teamed in shallow lifts. In some other respects the go-carts are superior to the former kind, particularly on soft or new made roads, where they can be drawn with more ease than the three-wheeled cart, in which the third wheel adds considerably to the horse's draught. On the other hand, the go-carts are not so easily managed as the three-wheeled contrivance, which may very safely be entrusted to a boy; but the go-cart requires a man, or at all events a strong and active youth, to hold up the shafts and manage the horse, which is travelling before him. Of all the carts I have tried for the removal of earth to short distances, I never found any to equal in convenience a small go-cart of light construction, contrived and used by myself on the Union Canal, in Scotland. These carts, of which a drawing and description are given in the recent celebrated publication by Mr. Weale, of the "Engineering Works of Great Britain," contained each about 18 cube feet of earth, and were run by men with great ease on light rails,* laid down on longitudinal bearing planks, 10 inches wide, 3 inches thick, supported on wooden sleepers. The tail-board is hung by hinges, and is disengaged and shut again by the man at the teaming-place, with-

* It may be necessary to explain that the rails here mentioned bore no resemblance to those used in railroads of the present day. They were simply flat bars of iron, fixed upon the bearing planks by nails and straps. To modern contractors engaged in large earthworks I should recommend the rail adopted by Mr. Gibbs, on the London and Croydon Railway, as being decidedly superior to every other with which I am acquainted. This rail was designed by Mr. Gibbs entirely to dispense with the use of chairs, and is accordingly fastened to the longitudinal bearers by screws passing through the broad base of the rail. Great solidity is thus secured, and the rail at the same time possesses the recommendation of being lighter, and more economical than any other hitherto adopted.

out quitting his station at the shafts: thus not only is much time saved in teaming, but the expense of it is also avoided.

Having determined, according to the particular circumstances of the case, the kind of waggon or cart to be employed in removing the earth from the cuttings to the embankments on the intended road, the attention of the engineer or surveyor must be directed to a still more important part in the business of estimating; namely, the precise nature of the earth with which the works are to be constructed.

It must be obvious, that the general name of the earth, such as clay, sand, gravel, or chalk, affords by no means a correct criterion by which to judge of its real nature; because all of these, and more particularly the clays, contain amongst themselves many shades of difference in respect of hardness and tenacity. The extent to which any particular earth is characterized by one or both of these qualities, determines the nature of the material in question; because they indicate the ease or the difficulty with which the earth can be broken up, and otherwise separated from the general mass, into pieces of suitable size for loading into carts.

The faculty of being able to pronounce correctly on the nature of the earth to be removed, can only be acquired from a long course of practice, which shall have afforded opportunities of witnessing the execution of earth-work in every different variety of circumstance and position. Such a course of practice can alone furnish the original data already mentioned, from which to determine the amount of labour required in the removal of different descriptions of earth. This of course is the same thing as to be able accurately to judge its precise nature, because upon this depends the extent of labour necessary to produce a certain effect. It is by no means sufficient to determine these data, as some have attempted to do, from the single isolated observation of one piece of work managed in a particular manner, which may be judicious or otherwise, according to circumstances. Nothing in fact is more common than to see the execution of earth-work, under the management of ignorant contractors and inexperienced gangsmen, costing from one-third to one-half more than it would under proper and judicious arrangements.

This may arise from the awkwardness and incompetency of the workmen, even when well provided with implements; and in many other cases, from the insufficient supply of working implements and horses, the want of good roads, and other requisites of the same kind. The difficulties occasioned by a narrow and confined system of management, adopted usually under a false impression of economy, will invariably produce, in the very best men, an effect so dispiriting that they cannot do more than half or two-thirds of the work, which a proper system of management would render them capable of performing.

By means of the practical experience to which I have alluded, and which cannot be otherwise acquired than from extensive observations on the progress of earth cuttings, the student will be able, on viewing the face of an open cutting, to determine how many yards per day of the earth, which the cutting exhibits, a good workman can fill into the vehicle intended for its removal. From the same experience also he will be able to judge upon another point of no less importance, namely, the extent of preparation which the earth must undergo in the way of breaking up, before it becomes ready for the fillers. The proportion of getters necessary to supply and keep constantly employed a given number of fillers being thus known, the data for valuing the price of any earth excavation are at once in possession of the engineer. He may now with confidence, after inspecting the trial pits and casual openings which are to be found in the neighbourhood of most public works, classify the various kinds of earth according to their several qualities, and determine for each the prices on which his estimates are to be framed.

If we consider, however, the extent of practical experience, and the variety of observation necessary to qualify an engineer thus to judge of the value of earth excavation, we shall be at no loss to account for the eternal difference of opinion amongst engineers in all that relates to the prices of the works under their control: nor for the same reason is there any thing at all surprising in the constant recurrence, session after session, of the extremely conflicting evidence brought before Parliament on the subject of estimates for public works. A great error into which students are apt to fall when attempting to acquire for themselves a knowledge of prices, arises from the supposition that they can, by observing personally the progress of one or two earth-works under their inspection, and by comparing the daily progress with the quantity of labour expended in the execution, arrive at the real cost of similar works in other situations. Nothing can be more erroneous than this; for such a course of observation does not even furnish data sufficient to determine the cost of the particular works which have been the subject of observation, much less of other works which may be considered analogous to those originally observed. In order to explain this, it must be remembered, that there are many circumstances in all earth excavations which occur to occasion expense to the principal contractor, and with which the gangsmen have nothing to do. Thus these circumstances, although most important as influencing very materially the price of the work, could never be known to the most scrutinizing inspector or time-keeper, unless instructed by the contractor himself. The execution of the work may be attended also by other circumstances, of which the young engineer may observe the existence without being able to estimate their effect on the price of the work. For example: a continuance of unfavourable weather may occasion a dreadful increase of outlay in the formation of proper roads to carry the excavated earth, in addition to extraordinary wear and tear of the working implements, and the destruction of horses, carts, and gear of every description. Sometimes the sliding and giving way of embankments, and accidents of the same kind in the cuttings, and sometimes the necessity for unexpected drainage to keep the work dry during its progress, will contribute very heavily to increase the price of the work beyond what might appear to a casual observer to be the cost of its execution.

One grand cause, however, I have not yet mentioned, although it ranks in importance before all the others, and this is the practice of forcing the works, with the view of completing them within less than a fair and reasonable time for their performance. This practice, which is not only most destructive to a contractor's interest, but more conducive than any other to the extravagant cost of many great public works, is not unfrequently persisted in during the worst seasons of the year, and this to such an extent as to render it necessary to carry on the work night and day throughout the year.

It would be no difficult task to enumerate many other circumstances which would render the cost of any particular work very different, according as these happened to be favourable, or otherwise. It is probable, however, that enough has been already said to show, that the capacity of justly appreciating the influence of these circumstances in varying the price of earth-work, is confined almost entirely to the experienced contractor, who, during a long and intimate acquaintance with the subject, has drawn his experience from the actual profit or loss he has himself sustained under like circumstances.

The preceding observations, on the difficulty of correctly estimating the prices of earth-work, are by no means intended to deter the unpractised engineer or surveyor from attempting to form an estimate of its cost. They are simply designed to show the fallacy of assuming any fixed prices as applicable to all work of the same kind in every situation; and if they suggest to the younger members of the profession the necessity of proceeding on more minute and particular data than those usually taken, the intention which has given rise to them will be fully accomplished. With this explanation, I proceed to the details which have been already alluded to, as calculated to simplify the general business of estimating earth-work.

The various strata which are found in excavations made for roads, railways, and canals, may be classed under the following heads:

1st. Underhanded soft earths, such as peat, soft marl, ouze, sand, gravel, common mould, and some of the softer clays.

2nd. Grafting earths, comprising the first layer, or one draw in depth of any tenacious earth; also all clays requiring the use of a foot-iron to force the grafting tool into the earth, which can be more readily displaced and filled in this way than by the method of falling it into the cutting.

3rd. The earths which require getting, of which kind are all the hard clays, hard gravel, chalk, common rocks of every description, and in fact every variety of earth which cannot be filled either by the common shovel or grafting tool alone, but requires, by some means or other, to be forced to the bottom of the cutting, and broken to pieces.

In judging the cost of excavating any of these earths, there are two things to be observed, namely, the quantity which can be filled by a given amount of labour, and the number of getters necessary to keep that same amount of labour in operation.

The first class of earths described above, namely, the *underhanded stuff*, is filled into carts, or thrown to a distance by the workman standing on the lower level of the earth which he has to remove, and taking up the material on his tool without any other exertion than that of raising each spade or shovel-full, and either placing it in a cart, or throwing it to a distance, as may be required. It may be assumed that a good workman can easily fill 20 cube yards per day of *underhanded stuff;* and 2*d.* per yard would therefore be a fair and ample remuneration to be paid to the work man alone for his labour. The contractor's expense for materials, superintendence, and contingencies, must be an after consideration, and will vary considerably, according to the quantity of work to be executed—whether it be wet or dry—the facility of obtaining workmen, and the accommodation which the country will afford them in the way of lodging—the kind of land and water-carriage by means of which the working implements must be brought on the ground—according to the season of the year—and to many other circumstances, which must render it extremely fallacious to name any fixed sum, either as a per centage or other charge, which will in all cases be found a remunerating price.

The second class of earth, or that termed *grafting stuff*, is removed by a man standing above it, and forcing his tool (which thence derives its name of grafting, or more properly *graffing*, tool) into the earth by a stamp of his foot, which has the shoe protected with a piece of well tempered steel, fastened on with leather straps, and called a foot-iron. The increased time occupied in driving the tool into these grafting earths, may be taken as nearly equal as possible to the additional labour of one getter for every two fillers employed; or in other words, it requires three men in grafting earths to perform the same work as two men in underhanded stuff: or again, the price of 3*d.* per yard on the former will only afford the same wages as 2*d.* on the latter.

The third class, or *getting stuff*, presents greater variety than can possibly be found in the two former classes together. Even the clays alone are not more various in colour than in their different degrees of tenacity and solidity. They range through every grade of these qualities, from the softer kinds, which are usually grafted, up to the hard blue clays, which I have found more troublesome and expensive to remove than some of the hardest whin-stone and granite rocks. These latter I would rather encounter than some of the clays I have met with in the course of my practice in earth excavations. It has been before assumed, that a man can easily fill twenty yards of underhanded stuff in a day, and it might appear at first sight that (in the case of getting earths) after the stuff has been broken in pieces by the getters, it can be filled with the same facility as underhanded stuff. This however is not the case; for I can affirm, with great confidence, that men filling earth, requiring for instance two getters to each filler, and equal both in skill and strength to the same number working in underhanded earth, will not fill more than half the quantity, or about ten yards per man per day. This great difference in the mere labour of filling the two kinds of earth, arises in some degree from the inconvenience of working in the very limited space to which the fillers are necessarily confined at the face of deep cuttings, and the frequent removals which the men in this small space are obliged to make from one particular heap of earth to another. The crowded state of the filling face is further increased by the pickmen, each of whom will occupy the same space as two fillers. A considerable time is lost by all the fillers previous to every fall of earth; for whilst the piles are being driven down, it is impossible for the fillers to continue at work below. The fillers are also occasionally kept waiting until the earth, after its fall, is picked to pieces ready for filling. Lastly, the trouble of shifting roads is much increased in removing earth which is thus brought down in falls, and from these causes combined, the labour required to remove a given quantity of getting stuff is about double the labour necessary to remove the same quantity of underhanded material; and it is a certain fact, that the more expensive any description of earth may be to get, it is always more expensive to fill.

In order to bring down falls of the getting earth, and prepare it for the fillers, the process of undermining is resorted to. When a longitudinal hollow in the direction of the mass to be brought down has been scooped out at the bottom of the cutting by properly pointed pickaxes, and the mass has been further separated from the great body of the earth by transverse upright chambers, which are also either picked or dug out by the grafting tool, a row of piles, about three feet, or three feet and a half in length, and about five inches diameter, properly shod and hooped with iron, is then driven down at the top of the mass by a beetle of suitable size, and by these means it is soon forced to the bottom of the cutting.

If the earth be tolerably brittle and inadhesive, it is sometimes broken into several pieces, and rendered loose by the violence of the fall. Gravel, for instance, is very easily filled when once it has been forced to the bottom of the cutting; but most of the clays must afterwards be picked to pieces by pickaxes before they can be filled into the waggons.

It will readily be seen that where it requires three men to get and fill 10 cube yards of earth per day, the price of their labour alone will amount to 1*s.* per cube yard; and accordingly it is by no means an uncommon case to find a contractor paying his men this high price when he is so unfortunate as to encounter these kinds of clay. In the case we have supposed, where two getters are required to supply each filler, it is evident that the getting alone will cost double as much as the filling, and the separate cost of each will appear from the following statement:

	s.	*d.*
One filler removes 10 yards at 4*d.*	3	4
Two getters prepare 10 yards at 8*d.*	6	8
Price of getting and filling 10 cube yards . .	10	0

which is equivalent to the pay of three men at 3*s.* 4*d.* each.

So much for the cost of the labour alone; and with respect to the contractor's remuneration, it must be observed, that this ought to be estimated at a very different amount from that which he would find sufficient to clear all the charges of removing underhanded earths. In the latter case, his furnishings of materials need only consist of the barrows and planks or carts for conveying the earth from the cutting; but in removing hard stuff which requires getting, he is obliged to provide picks, beetles, and piles, and to keep these constantly sharpened and in good repair. In addition to this, a very considerable increase of wear and tear will be occasioned to the waggons, carts, or barrows, and must of course be estimated accordingly.

In connection with the increased expense of removing the harder kinds of earth, it may not be considered irrelevant to glance at the general effect which will be produced in respect to the time of executing any work that requires much getting, as compared with other kinds of work more favourable in their nature. For instance; if a cutting consist of underhanded earth which requires no getting, it may be assumed that fifty men will fill 1000 yards per day; but if the earth require two getters to each filler, it is evident that thirty-three out of the fifty must be employed in bringing down falls, and breaking up the earth for the remaining seventeen, which number alone will continue to be actually engaged in filling. Suppose now that a man can fill 10 yards daily of this earth, the quantity excavated by the whole fifty men will only amount to 170 yards, or about one-sixth of the quantity which could be excavated of underhanded earth. We perceive therefore the necessity of perfectly ascertaining the nature of any excavation before attempting to estimate either the *time* or the *cost* of its execution.

In assuming that a workman will not be able to fill more than 10 yards a day of earth which requires getting, it must be understood that this applies to earth of very unfavourable character; but if the earth be of such a quality as to require say one getter to two fillers, the labour of each filler may be averaged at

13 or 14 yards per day, and the cost of filling in this case will therefore amount to about 3*d.* per yard.

With respect to the price of teaming, this may be fairly averaged at 1*d.* per yard in estimating; but this must be varied according to the nature of the stuff. Sand, gravel, chalk, and clay, when dry, will always team well; but any of these earths in a wet state will become clammy and adhesive to a degree which increases the time, the trouble, and expense of teaming.

We may now proceed to establish the general rule for estimating the price of earth-work, founded upon the data which have been already laid down, and which, for the sake of greater clearness, it may be necessary to recapitulate. In earth which requires one getter to two fillers, the work done by the three men will be $14 \times 2 = 28$ yards. In earth which requires two getters to one filler, the work done by the three men will amount to 10 yards; and taking the mean of these two amounts, we may assume the work of two men in earth requiring one getter to one filler, equivalent to 18 yards. Now it is evident, that in order to afford the same wages to the workmen in each of these three cases, the price to be paid for the work must always be inversely proportional to the amount of that work. Thus, if the value of three men's labour for one day be taken at 10*s.*, or 120 pence, we have $\frac{120}{28}$, $\frac{120}{10}$, and $\frac{120}{18}$ for the price in pence of getting and filling the three kinds of earth respectively which have been described above.

The price for the worst of the three kinds, namely, that which requires one getter to two fillers, will therefore be $\frac{120}{10} = 12d.$ per cube yard. The price for the next in order, or that which requires equal numbers of getters and fillers, will be $\frac{120}{18} = 6\frac{2}{3}$ pence per cube yard; and the price for the best of the three, or that which requires one getter to two fillers, will be $\frac{120}{28} = 4\frac{2}{7}$ pence per cube yard. In general terms, if F and G represent respectively the number of fillers and getters required to excavate any given quantity of earth, which may be represented by q, and if p express the wages of a single workman for the time which is occupied in excavating the quantity q, then we have $\frac{p\,(F + G)}{q} = P$ the price per yard of excavating the earth in question.

In proceeding to a brief review of the other descriptions of labour required in the construction of roads, the next in importance for roads constructed with a pitched foundation is probably that connected with the supply of stones proper for this purpose. In any country where an open quarry exists from which stone, no matter of what quality, is procured for building purposes, there will always be found an abundance of waste rubble, or small blocks of stone, which cannot be used for buildings of any description, and which therefore are usually removed into the bottom of the quarry as useless material. This kind of waste stone is perfectly adapted for pitching the foundations of roads, since it is only required that the stones shall range in depth from four to seven or eight inches from the apex or highest point to the base, and that the base shall not exceed about six inches in width. In any quarries producing stone for building purposes, it will surely not be too low an estimate to assume that rubble of the kind I have described may be bought on the ground for about 3*d*. per ton, since for any other purpose it would scarcely be worth the expense of carting. Beds of rock, which may be used for road pitching, are frequently found cropping out to the surface of the ground in places where stone is abundant. In such situations, even where no regular quarry has been opened, the stone may be got for about 3*d*. or 4*d*. a load. In some places where the difficulties of procuring stone have been greater, I have paid from 6*d.* to 1*s.* a load, this quantity being sufficient to pitch about five superficial yards of road. The charge of 1*s.* per ton for pitching stones is decidedly high, and very much above the usual cost for which they may be procured. The price of loading and carting the stone from the quarries may be taken on an average at about 1*s.* per cube yard per mile. Of course, if the distance of carriage be short, and the repetition during the day of the loading and unloading be more frequent, the cost of carriage will be somewhat in excess of this sum; and on the contrary, a long distance, estimated according to this rate, will afford the carrier too much profit. Probably for any distance of carriage between one and two miles, the price mentioned above will be found a fair remuneration, but for shorter distances than a mile it will be far from a profitable bargain to the carrier. In any estimate of carriage, however, the situation of the quarry with respect to the road where the stones are to be used must be taken into consideration, because the state of the intermediate roads on which the stones are to be drawn is of great consequence. The price of 1*s.* per yard per mile will be found reasonable in any country where the road leading from the quarry is a tolerably fair country road, notwithstanding the ruts may in some places be none of the smoothest, and the bottom none of the hardest. Where unreasonable inclinations however exist on the communicating roads, the price will be rather insufficient.

The labour of pitching the road after the stones have been carted and laid down ready for use, is worth about 1¼*d.* per superficial yard. The price of procuring gravel for the road covering, although materially affected by the circumstances which have been alluded to at the beginning of this chapter, will not frequently exceed 2*s*. per cube yard at the pit, after the gravel has been cleaned and sorted. I have however known instances, where the gravel required a great deal of preparation, in the way of breaking, screening, and even washing, in which the price of 4*s*. per yard has been paid, and this is the highest price with which I am acquainted. Nothing less than actual examination of the country, assisted by local information, will enable the surveyor to estimate, in a new country, the exact price to be paid for the gravel at the pit; but this price being once known, the value of the material laid down on the road may be taken at a shilling per yard per mile of carriage, in addition to the price at the pit.

All brickwork required for culverts, bridges, shafts, or retaining walls, should be paid for by measure; and here the price will depend upon the rate of workmen's wages and upon the facilities of obtaining bricks, lime, and sand. The lowest price however at which the brickwork necessary for roads should be estimated, is 11*l*. per rod of standard measure; because, should the work be undertaken at any lower price, the surveyor will have much trouble to prevent the introduction either of inferior materials or improper workmanship. This is far from being the average cost of the brickwork in road improvements. In many instances where the work is not very massive, and consists of a large proportion of circular building, and where at the same time the building materials are expensive, the price amounts to 15*l*. a rod, and the contractor even then is sometimes indifferently remunerated. The variation of price is often occasioned entirely by the different circumstances under which the bricks can be obtained and brought upon the ground. For instance; I have myself bought bricks at one guinea per thousand, and at other times have paid as much as two guineas, in both cases exclusive of carriage. Suppose now that the cheap bricks may be obtained close to the work; and on the other hand consider a case where a long distance of bad road intervenes between brick-kilns, where an expensive kind of brick is supplied, and the site where the building is to be constructed: it is obvious that a vast difference will be found in the prices of the brick-work, under these different circumstances, which sometimes occasion work to cost more than double the price in a more favourable locality.

The building price alone to be paid to the workman may be taken on the average at about two guineas per rod, and the furnishing of lime and sand at two guineas more. It may be estimated that the quantity of 4500 bricks will be necessary to finish a rod of brickwork, and the price of this quantity at the kilns, together with the cost of carriage at 1*s.* per ton per mile, being added to the four guineas assumed for workmanship, lime, and sand, the price per rod will be obtained with sufficient accuracy for the approximate estimate; but of course a per centage must be added for the contractor's profit and the supply of materials.

Longitudinal side drains, three feet deep, with five-inch sough and tile laid in the bottom, averaging fifteen inches wide, and filled to the top with clean broken or boulder stones, may be estimated at from 1*s.* 6*d.* to 2*s.* 6*d.* per lineal yard, according to the facilities of obtaining the stones. Mitre drains will cost from 6*d.* to 1*s.* 3*d.* per lineal yard.

Forming a footpath in the best manner, six feet in width, with a sod facing in front, will vary in price from 1*s.* to 2*s.* 6*d.* per lineal yard.

Having now gone through most of the works which the surveyor is usually called on to estimate in carrying into effect the improvement of roads, and made such practical observations upon the general method which ought to be followed in estimating works, as will enable the young surveyor to pronounce with some confidence upon the cost of any improvements he is about to undertake, I shall proceed to lay down a form of estimate which will serve, in some measure, to illustrate the use of the preceding observations.

The road for which the following estimate has been formed we shall suppose to be thirty feet wide, to be equally well constructed with any part of the London and Holyhead road, to have a footpath six feet wide on the north side, and to be defined on the south side by a verge, or raised ridge, elevated from the water table up to the height of the centre of the road; the footpath and verge to have a sod neatly and firmly laid on their front facing. We shall suppose the extent of road to be improved, or newly constructed, to be one mile in length, and the earth-work to consist of 20,000 yards of cutting of the following kinds:—2000 yards of grafting stuff, to be wheeled two stages of 20 yards each; 5000 yards of getting stuff, to be removed two stages of 80 yards each, and requiring one getter to three fillers; 5000 yards of the same stuff, to be removed by go-carts 3 stages, or 240 yards; the remaining 8000 yards being bad stuff, to go 4 stages by go-carts, and requires two getters to each filler.

Probable Estimate of the Cost.

Earthwork.

		£	s.	d
Grafting earth will cost per yard for filling . . .	3*d*.			
Wheeling by barrows two stages	2			
Contractor's material, profit, &c.	1			
2000 at	6*d*.	50	0	0
Carried forward		50	0	0

	£	s.	d
Brought forward	50	0	0
Getting stuff requiring one getter to three fillers, to be removed by go-carts two stages, or 160 yards, will cost filling 3*d*., removing 2*d*., getting 1*d*., teaming 1*d*.; contractor for sharpening picks, furnishing beetles, &c. ½*d*., furnishing carts and light rails 1½*d*.; in all 9*d*. per yard.			
5000 yards at 9*d*.	187	10	0
Getting stuff also requiring one getter to three fillers, to be run by carts three stages, will cost filling as before 3*d*., removing 3*d*., getting 1*d*., teaming 1*d*.; contractor as before for furnishings 2*d*.; in all 10*d*. per yard.			
5000 yards at 10*d*.	208	6	8
Hard getting clay requiring two getters to each filler, and of which each filler can only fill 10 yards per day, will cost for filling 4*d*., getting 8*d*., furnishing picks, piles, beetles, &c. 1½*d*., furnishing go-carts and rails 3*d*., carriage four stages 4*d*., teaming 1*d*.; in all 1*s*. 9½*d*. per yard.			
8000 yards at 1*s*. 9½*d*.	716	13	4
Road Pitching.			
Furnishing the stones which cost in the quarry 4*d*. per ton, and to be carted a distance of two miles, at 1*s*. per ton per mile, making in all 2*s*. 4*d*. per mile; then if one ton will complete 3½ superficial yards of pitching six inches deep, the quantity required for one mile in length will be $\frac{1760 \times 10}{3\frac{1}{2}}$ = 5029 tons, at 2*s*. 4*d*.	586	14	4
Labour of pitching one mile in length, at 1¼*d*. per superficial yard, or 17,600 yards at 1¼*d*.	91	13	4
Footpath and Verge.			
Forming and completing footpath one mile in length, or 1760 yards, at 1*s*. 9*d*.	154	0	0
Forming verge on the opposite side of the road, eighteen inches wide and nine inches high.			
1760 lineal yards at 4*d*.	29	6	8
Drainage.			
A longitudinal side drain on each side of the road, three feet deep, and filled with clean stones broken			
Carried forward	2024	4	4

	£	s.	d
Brought forward	2024	4	4
to the proper size, including a five-inch sough and tile channel to be laid in the bottom.			
3520 lineal yards at 1*s*. 6*d*.	264	0	0
Mitre drains at intervals of 40 yards, each drain being 12 yards long, will cost, at 1*s*. per yard, 12*s*.			
44 drains at 12*s*. each	26	8	0
Road Covering.			
Gravel to be laid down six inches in depth, a ton of which will cover about 4 superficial yards of the road, hence a mile in length will require 4400 tons; then this will cost at the quarry 2*s*. 6*d*. per ton, carriage two miles 2*s*., spreading on the road 6*d*.; in all 5*s*. per ton.			
4400 tons at 5*s*.	1100	0	0
Brick-work.			
In this mile of road it is necessary to build two culverts, and other brick-work is introduced; altogether 24 rods of work, at 12*l*. 10*s*.	300	0	0
	3714	12	4
Contractor's profit for superintendence, unforeseen circumstances in the work, and every possible contingency, at 20 per cent.	742	18	6
	£4457	10	10

I beg to observe, with reference to the preceding estimate, that although on many long lines of road the quantities of cutting and embanking, at particular parts, far exceed the amount I have assumed of 20,000 yards per mile, on the other hand it must be remembered, that in many districts the quantity of cutting will not be found nearly so great on an average of many miles of road communication. Again, the prices which have been assumed are of course hypothetical; but of one thing I am certain, that I have not fallen into the error which so many hundreds have committed, of underrating the cost of works to be carried into execution. I believe that in general the materials can be obtained for less than I have estimated; and throughout the whole of my statements, I have carefully guarded against the danger of misleading those who may hereafter embark in works of the kind I have been describing. Whether it be the surveyor pledging himself to his employers, the promoters of these works expecting to see their intentions carried into effect for the estimate laid before them, or the contractor seeking to derive a reasonable remuneration for executing the works—to all and each I would say, that they may safely depend upon the fairness and candour of the statements I have made, since these are the result of a long course of constant practice and experience, during which I have bestowed unwearied attention upon the methods of estimating engineering works under every possible variety.

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